R-3825-1

TECHNICAL MANUAL

ENGINE DATA

J-2 ROCKET ENGINE

(ROCKETDYNE)

CHANGE NOTICE

LATEST CHANGED PAGES SUPERSEDE THE SAME PAGES OF PREVIOUS DATE

Insert changed pages into basic publication. Destroy superseded pages.

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LIST OF EFFECTIVE PAGES

NOTE The portion of the text affected by the changes is indicated by a vertical line in the outer margins of the page

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8-20	3	29 Nov 67
8-21	0	Original
8-22	4	10 Jul 68
8-23	7	4 Dec 69
8-24	4	10 Jul 68
8-25	0	Original
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11-2 thru 11-6	7	4 Dec 69
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Upon receipt of the second and subsequent changes to this technical manual, personnel responsible for maintaining this publication in current status will ascertain that all previous changes have been received and incorporated. Action should be taken promptly if the publication is incomplete.

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INTRODUCTION

This manual is one of the R-3825-series technical manuals prepared to provide official Rocketdyne field support documentation for the operation and maintenance of the J-2 Rocket Engine, Part Number 103826, Serial Numbers J-2039-1 through J-2152, and its related ground support equipment, designed and manufactured by Rocketdyne, a division of North American Rockwell Corporation, 6633 Canoga Avenue, Canoga Park, California 91304. The information in these manuals was prepared by Logistics Product Support Department of Rocketdyne.

The manuals are used to best advantage when each manual is current and complete (see figure 1) and the purpose and scope of each manual is known. The manuals in this series, and the nature of the data each provides, are found in the manuals' contents and support function chart.

1. J-2 MANUALS--THEIR SUPPORT FUNCTIONS.

The contents and support function chart lists all J-2 series technical manuals, describes the support function each manual serves, and lists the section titles of each manual. The chart also explains how the technical data in each manual relates to the support of the engine and its ground support equipment throughout a normal engine flow, as well as during unscheduled maintenance tasks. Information appearing in one manual is not duplicated in another. Thus, information on the description, operation, and maintenance of ground support equipment is in R-3825-5. However, the instructions for servicing the engine using ground support equipment are in R-3825-3 and R-3825-1B.

Manual	Contents and Support Function	Section and Title
R-3825-1 J-2 Rocket Engine Data	This manual contains a description and theory of operation of the engine, its systems, and its components; mass properties and design load criteria, including engine weight, gimbaled mass, center of gravity, and moment of inertia for the basic engine and its accessories; and customer connections. The manual serves to familiarize the reader with the design and operation of the J-2 engine and serves as a training aid document.	See detailed table of contents for this manual.
R-3825-1B J-2 Rocket Engine Operating Instructions	This manual contains authorized field operating requirements that affect flight engines during their normal flow from engine receipt through vehicle launch, and those procedures recommended by Rocketdyne that support these requirements most effectively. All specific and general requirements for activities to be performed and acceptability criteria for these activities are included along with the limits, special constraints, safety precautions, and correct sequences required to satisfactorily accomplish the activities.	I Operating Requirements II General Requirements III Operating Procedures

Manual	Contents and Support Function	Section and Title	
R-3825-3, Volume I J-2 Rocket Engine Maintenance and Repair	This manual contains requirements and procedures for handling; component removal and installation; cleaning; post-maintenance test requirements; the safety precautions to be observed; and information on the tools, materials, electrical power, and pressurizing agents necessary to perform the tasks.	I	General Maintenance and Repair
		II	Handling
		III	Component Removal and Installation
		IV	Post-Maintenance Test Requirements
		V	Preparation of Components Handler Equipment for Use
		VI	In-Place Tube Welding
R-3825-3, Volume II J-2 Rocket Engine Maintenance and Repair	This manual contains requirements and procedures for component bench testing and repair; the safety precautions to be observed; and information on the tools, materials, electrical power, and pressurizing agents necessary to perform the tasks.	I	Air Filler Valve
		II	Armored Harness
		III	Augmented and Gas Generator Spark Igniter Cables
		IV	Electrical Control Assembly
		V	Flight Instrumentation Package
		VI	Fuel Turbopump
		VII	Heat Exchanger
		VIII	Helium Fill Check Valve
		IX	Ignition Detector Probe
		X	Insulation
		XI	Integral Hydrogen-Helium Start Tank
		XII	Mainstage OK Pressure Switch
		XIII	Oxidizer Turbopump
		XIV	Purge and Seal Drain Check Valves
		XV	Solenoid Valves
		XVI	Start Tank Discharge Valve
		XVII	Start Tank Refill Check Valve Manifold 307599-41
		XVIII	Start Tank Support and Fill Valve
		XIX	Thrust Chamber
		XX	Transducers
		XXI	Vent Port Check Valves

Manual	Contents and Support Function	Section and Title	
R-3825-4 J-2 Rocket Engine Illustrated Parts Breakdown	This manual contains related illustrations and columnar listings of all parts of the engine that can be replaced at field sites as determined by the maintenance concept; definitions and designations of source, maintenance, repairability, interchangeability, and usable-on codes; information pertaining to retrofit modifications; identification of next-higher assemblies; identification of Reference Designation Indexes.	I	Introduction
		II	Group Assembly Parts List
		III	Numerical Index
R-3825-5, Volume I J-2 Rocket Engine Ground Support Equipment Maintenance and Repair	This manual contains a description of engine servicing, handling, and test equipment; procedures for performing maintenance and checkout tasks; and inspection and maintenance requirements tables.	I	Maintenance and Repair
		II	Thrust Chamber Throat Plug Kit G3120
		III	Thrust Chamber Protective Pad 9016705
		IV	Electrical Checkout Console G1037
		V	Flight Instrumentation Checkout Console G1035
		VI	Data Recorder Console G3121
		VII	Engine Test Plates; Adapters, and Tools
		VIII	Extended Range Vibration Safety Cutoff Set G1038
		IX	Pneumatic Console G3106
		X	Pneumatic Flow Tester G3104
		XI	Simulator Panel 9024480-11
		XII	Components Test Console G3107
		XIII	Automatic Inert Gas Arc Welding Set G3128
		XIV	Single Head Special Tool Kit G3127
		XV	Propellant Utilization Valve Voltage Adjust and Monitoring Test Unit 9025664

Manual	Contents and Support Function	Section and Title	
R-3825-5, Volume II J-2 Rocket Engine Ground Support Equipment Maintenance and Repair	This manual contains a description of engine servicing, handling, and test equipment; procedures for performing maintenance and checkout tasks; and inspection and maintenance requirements tables.	I	Miscellaneous Tools
		II	Gas Generator High-Low Temperature Cutoff Panel G1047
		III	Outboard Engine Restrainer G4066
		IV	Film-Cooled Diffuser G4070
		V	Components Adapter Set 9016796
		VI	Liquid Nitrogen Service Unit 2425000
		VII	Electrical Interface Support 9024460
		VIII	Spark Monitor/Overspeed Cutoff Panel G1045
		IX	Component Slings
		X	Spark Monitor Turbine Overspeed Cutoff Test Set 9024499
		XI	Ignition Detector Set 99-9026355
		XII	Components Maintenance Sets/Kits
		XIII	Vibration Safety Cutoff Test Set 9024498
		XIV	Hot-Gas Temperature Transducers NA5-27323T4 and NA5-27342T3
		XV	Amplifier Mounting Panel 9024500
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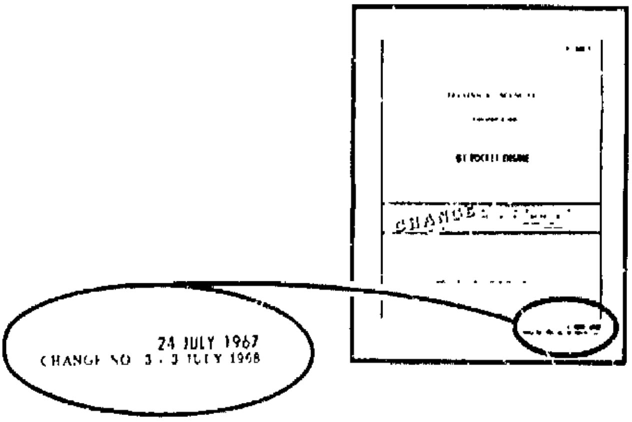
		XIX	Turbopump Sling
		XX	Propellant Inlet Duct Null Adjuster Set 9024540
		XXI	Inlet Duct Support Frame Installing Tool Kit 9025150
		XXII	Engine Handler G4064
		XXIII	Engine Vertical Installer G4035
		XXIV	Turbopump Maintenance Stands
		XXV	Turbopump Maintenance Sets
		XXVI	Sequence Controller and Oxidizer Heat Exchangers Handlers
		XXVII	Propellant Inlet Duct Handlers

Manual	Contents and Support Function	Section and Title	
R-3825-5, Volume II (cont)		XXVIII	Propellant Feed System Handlers
		XXIX	Start Tank Installer 9016783
		XXX	Fluid Lines Interface Support 9020628 and Fluid Lines Interface Arm Support 9026988
		XXXI	Thrust Chamber Seal Balloon 9016720
		XXXII	Spark Igniter Cable Pressurization Tool Kit 9025425
		XXXIII	Engine Components Installers

USE YOUR MANUAL ONLY IF CURRENT AND COMPLETE

Manuals that are not current and complete are not authoritative documents and are not to be used. The following outlines the method for determining whether your manual is current and complete.

A. DETERMINING CURRENCY. To be sure that yours is the latest issue of the manual, refer to Configuration Identification & Status Report , which is revised monthly and lists the technical manual numbers, titles, unincorporated supplements, and latest change or revision dates. Your manual must have a title page with the same or later date than the date shown in the Configuration Identification & Status Report. Your manual must also include the unincorporated supplements listed in the Configuration Identification & Status Report, or if your manual is later than shown in the report, the unincorporated supplements listed in the Manual Data Supplement Record in your manual. If your title page incorporates two dates as illustrated below, compare the change (lower) date. If your manual is not current, obtain a current copy through your technical manual supply system.

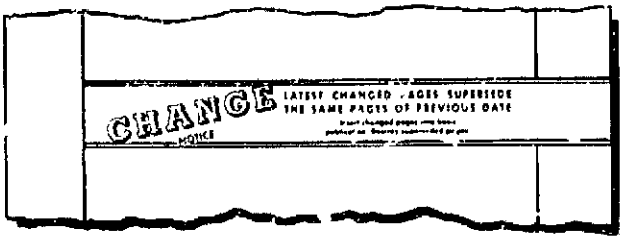


B. DETERMINING COMPLETENESS. To be sure that your manual is complete, make a page-by-page comparison of its pages to those listed in the List of Effective Pages. The List of Effective Pages, which shows the change status since the basic issue or last revision, is found on the alphabetically lettered page(s) immediately following the title page. All pages, except supplements, are listed with their issue dates. Manual pages that are dated must have the same date as that appearing in the List of Effective Pages for that page. Unchanged pages are listed as "original" and are not dated.

HOW TO KEEP YOUR MANUAL UP-TO-DATE

As design changes are made to the rocket engine and ground support equipment and better methods of maintenance are discovered, your manual is periodically changed, revised, or supplemented. The following steps will help you keep your manual up-to-date:

A. CHANGES. Updating by adding to or partially replacing existing pages is defined as a change. Changes can be identified by the change notice on the new title page.



To collate a change, refer to the Filing Instructions sheet issued with the manual and proceed as follows:

1. Remove the pages listed in the "Remove" column of the Filing Instructions sheet from the manual and destroy them. Do not concern yourself with the data on the opposite side of the deleted page since, if this date is not deleted, it is replaced in the change package.
2. Insert all pages listed in the "Insert" column of the Filing Instructions sheet in sequence. Pages with a suffix letter are inserted in alphabetical order following the page with the same basic number; for example, pages 3-14A, 3-14B, etc, follow page 3-14.

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Figure 1. How to Maintain Your Manual (Sheet 1 of 2)

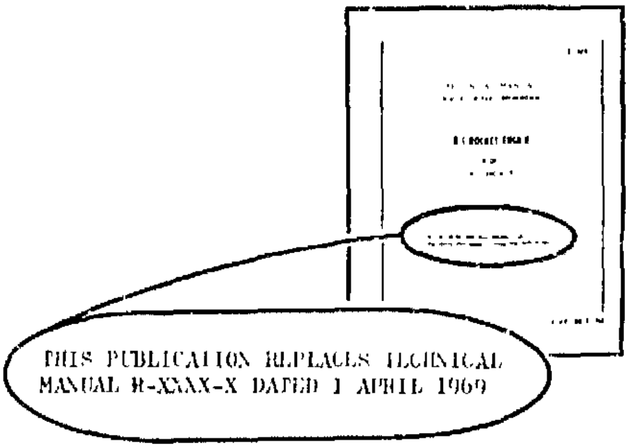
3. If you are unsure of the status of any page or pages, refer to the List of Effective Pages and make sure your manual contains pages (with the corresponding change dates) listed in the List of Effective Pages.

4. Remove manual supplements that have been incorporated.

NOTE

Incorporated supplements can be determined by reviewing the newly issued Manual Data Supplement Record.

B. REVISIONS. Updating by replacing all the existing pages of a manual is defined as a revision. Revisions can be identified by the replacement notice on the new title page.



To collate a revision, proceed as follows:

1. Remove and destroy all existing pages of your manual except Manual Data Supplements that have not been incorporated.

NOTE

Unincorporated supplements can be identified by reviewing the Manual Data Supplement Record supplied in the revision.

2. Insert the new pages in your cover.

C. SUPPLEMENTS. Updating that authorizes the addition to, or alteration of, the existing data in your manual is defined as a Manual Data Supplement. Information on how to insert supplements is found in the supplements.

HOW TO KEEP ABREAST OF THE LATEST CHANGES TO TECHNICAL DATA

Changes and/or additions to technical data are identified by a vertical bar (change bar) in the margin of the page adjacent to the changed data. A direct comparison between the new (identified by the change bar) and the old data will help you in identifying specific changes made.

GEN-NASA-2

Figure 1. How to Maintain Your Manual (Sheet 2 of 2)

2. CONFIGURATION IDENTIFICATION.

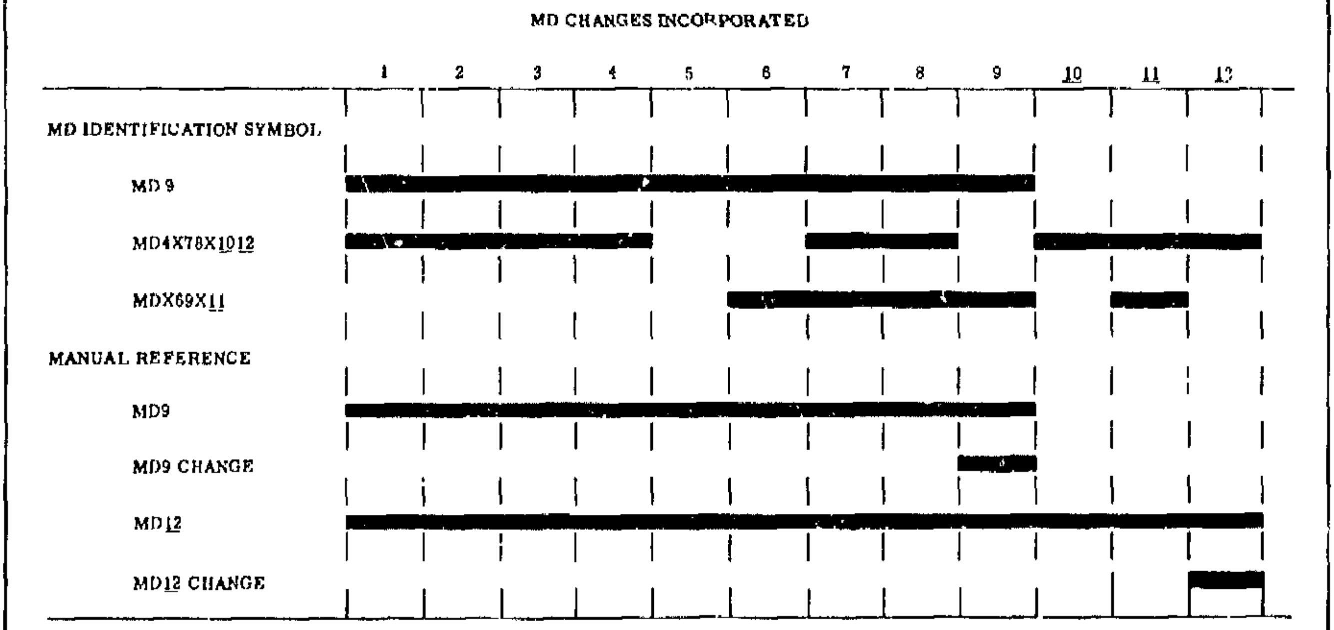
EQUIPMENT CONFIGURATION. The MD identification symbol and the equipment model designation indicate the configuration of the equipment and distinguish it from models incorporating different changes and from basic models. A basic, unchanged configuration of the equipment has no MD identification symbol. MD identification symbols are added as changes affecting configuration are incorporated into the equipment. The MD identification symbol is stamped on the MD plate, which is mounted near the engine nameplate.

MD IDENTIFICATION SYMBOLS. The MD identification symbol is a composite number representing all the changes affecting configuration (MD changes) that are incorporated or not incorporated into the equipment. The symbol represents a consecutively numbered series of MD changes. Any MD change, or series of MD changes, not incorporated is represented by an "X." Multi-digit numbers are underlined. Two figures together represent the limits of a series of incorporated MD changes. Figure 2 illustrates how MD changes incorporated in the equipment are represented by the MD identification symbol.

MANUAL REFERENCE. A reference that appears in the manual may refer to a series of MD changes or to an individual MD change: for example, "MD9" refers to MD1 through MD9, but "MD9 change" refer to the individual MD change 9. This latter type of reference, which is illustrated in figure 2, identifies separate sets of information required by differences in configuration. When an MD reference appears in this manual, examine the MD identification symbol on the equipment to determine which set of information is applicable.

3. CONFIGURATION CHANGES--MANUAL EFFECTIVITY.

All approved ECPs (Engineering Change Proposals) and associated MD numbers applicable to the equipment covered in this manual are listed in figure 3. The date in the last column is the publication date of the manual during which the change made by the ECP was incorporated. When N/A is entered, the ECP does not change the data in the manual. Engine configuration information is in R-5788, Saturn J-2 Configuration & Status Report. Engine serial numbers within this manual are in accordance with Rocketdyne J-2 engine designation.



NOTE: A HORIZONTAL LINE WITHIN THE CHART INDICATES THE MD CHANGE REFERRED TO IN THE SYMBOL OR REFERENCE AT THE LEFT.

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Figure 2. MD System

Approved ECP Number	MD Number	Incorporated in Manual Dated	Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-12	1	N/A	J2-95	20	31 December 1964
J2-13	1	N/A	J2-96	72	N/A
J2-14	3	N/A	J2-97	25	13 May 1965
J2-15	1	N/A	J2-99	14	18 June 1964
J2-17	5	N/A	J2-100	10	31 December 1964
J2-18	6	18 June 1964	J2-101	27	N/A
J2-19	5	18 June 1964	J2-102	38	N/A
J2-20	64	18 June 1964	J2-103	8	N/A
J2-20R1	--	N/A	J2-105	26	N/A
J2-24	8	18 June 1964	J2-106	9	18 June 1964
J2-26	9	18 June 1964	J2-107	42	N/A
J2-31	9	18 June 1964	J2-108	37	26 February 1965
J2-33	77	N/A	J2-109	3	N/A
J2-36	1	N/A	J2-110	36	18 June 1964
J2-39	8	N/A	J2-112	13	N/A
J2-41	2	N/A	J2-113	34	18 June 1964
J2-44	61	18 June 1964	J2-115	32	N/A
J2-44R1	--	N/A	J2-117	9	N/A
J2-45	3	N/A	J2-121	9	N/A
J2-46	5	N/A	J2-122	8	N/A
J2-47	10	18 June 1964	J2-123	43	N/A
J2-48	28	18 June 1964	J2-124	60	N/A
J2-51	16	N/A	J2-125	56	N/A
J2-52	1	N/A	J2-126	3	N/A
J2-55	7	18 June 1964	J2-127	26	18 June 1964
J2-57	11	N/A	J2-128	53	N/A
J2-62	9	18 June 1964	J2-129	40	N/A
J2-63	77	N/A	J2-130	3	N/A
J2-64	9	18 June 1964	J2-139	23	26 February 1965
J2-66	26	18 June 1964	J2-140	41	18 June 1964
J2-67	14	18 June 1964	J2-141	9	N/A
J2-69	77	N/A	J2-146	9	N/A
J2-74	70	13 May 1965	J2-147	9	N/A
J2-75	18	N/A	J2-151	11	5 May 1965
J2-76	56	13 May 1965	J2-152	79	5 May 1965
J2-77	17	13 May 1965	J2-154	23	18 May 1964
J2-78	20	18 June 1964	J2-157	44	N/A
J2-79	55	26 February 1965	J2-158	51	N/A
J2-80	11	18 June 1964	J2-159	23	N/A
J2-81	9	18 June 1964	J2-160	47	N/A
J2-82	70, 109	13 May 1965	J2-161	68	26 February 1965
J2-84	48	N/A	J2-161R1	--	N/A
J2-85	8	18 June 1964	J2-161R2	--	N/A
J2-86	26	18 June 1964	J2-163	54	18 June 1964
J2-87	23	N/A	J2-164	37	N/A
J2-88	8	N/A	J2-166	45	N/A
J2-90	8	N/A	J2-167	46	N/A
J2-91	49	N/A	J2-172	59	26 February 1965
J2-92	8	18 June 1964	J2-173	3	18 June 1964
J2-94	77	18 June 1964	J2-174	57	13 May 1965

Figure 3. Configuration Changes--Manual Effectivity (Sheet 1 of 6)

Approved ECP Number	MD Number	Incorporated in Manual Dated	Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-181	9	N/A	J2-268	9	N/A
J2-185	80	N/A	J2-271	186	N/A
J2-186	69	N/A	J2-271R1	--	N/A
J2-188	3	N/A	J2-271R2	--	N/A
J2-191	64	13 May 1965	J2-271R3	--	N/A
J2-191R1	--	N/A	J2-280	56	26 February 1965
J2-195	88, 111	6 August 1965	J2-281	9	N/A
J2-195R1	--	N/A	J2-284	101	N/A
J2-195R2	--	N/A	J2-285	58	N/A
J2-195R3	--	N/A	J2-286	3	N/A
J2-195R4	--	N/A	J2-287	9	N/A
J2-196	9	N/A	J2-288	3	N/A
J2-198	3	N/A	J2-289	9	N/A
J2-199	97	N/A	J2-290	9	30 April 1965
J2-200	23	18 June 1964	J2-293	105	26 February 1965
J2-202	37	31 December 1964	J2-296	35	N/A
J2-204	56	N/A	J2-296R1	--	N/A
J2-207	--	31 December 1964	J2-298	50, 129	N/A
J2-218	56	13 May 1965	J2-298R1	--	N/A
J2-226	3	N/A	J2-300	107	N/A
J2-227	99, 104	31 December 1965	J2-303	56	N/A
J2-229	108	N/A	J2-306	9	N/A
J2-229R1	--	N/A	J2-307	9	N/A
J2-232	9	N/A	J2-308	56	N/A
J2-235	58	N/A	J2-310	137	25 October 1965
J2-236	72	N/A	J2-310R1	--	N/A
J2-240	3	18 June 1964	J2-310R2	--	N/A
J2-241	86	18 June 1964	J2-312	9	N/A
J2-243	19	4 September 1964	J2-313	119	N/A
J2-246	3	N/A	J2-315	70	N/A
J2-247	76	N/A	J2-316	19	13 May 1965
J2-248	106	13 May 1965	J2-317	9	13 May 1965
J2-249	84	N/A	J2-318	153	6 August 1965
J2-250	87	N/A	J2-318R1	--	N/A
J2-251	78	N/A	J2-319	123	N/A
J2-252	56, 94	N/A	J2-319R1	--	N/A
J2-254	88, 91	16 February 1966	J2-319R2	--	N/A
J2-254R1	--	N/A	J2-320	100	16 February 1966
J2-254R2	--	N/A	J2-320R1	--	N/A
J2-254R3	--	N/A	J2-321	118	N/A
J2-254R4	--	N/A	J2-322	116	N/A
J2-255	88, 187	16 February 1966	J2-329	133	6 August 1965
J2-255ER1	--	N/A	J2-329R1	--	N/A
J2-255ER2	--	N/A	J2-329R2	338	1[illegible] June 1969
J2-255ER3	--	N/A	J2-330	88	N/A
J2-255ER4	--	N/A	J2-331	117	N/A
J2-255ER5	--	N/A	J2-331R1	--	N/A
J2-257	9	N/A	J2-332	9	N/A
J2-259	64, 92	31 December 1964	J2-333	141	N/A
J2-260	38, 83, 85	N/A	J2-333R1	--	N/A

Figure 3. Configuration Changes--Manual Effectivity (Sheet 2 of 6)

Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-338	[illegible]	N/A
J2-340	9	N/A
J2-341	120	26 February 1965
J2-345	56, 125, 126	N/A
J2-345R1	--	N/A
J2-347	121	N/A
J2-348	122	13 May 1965
J2-350	15	N/A
J2-350R1	--	N/A
J2-351	124	N/A
J2-351R1	--	N/A
J2-352	56	N/A
J2-359	140	N/A
J2-359R1	--	N/A
J2-360	139	N/A
J2-360R1	--	N/A
J2-360R2	--	N/A
J2-361	30, 127	N/A
J2-362	131	N/A
J2-363	138	N/A
J2-363R1	--	N/A
J2-364	132	N/A
J2-365	142	N/A
J2-366	128	6 August 1965
J2-367	70	N/A
J2-368	130	N/A
J2-368R1	--	N/A
J2-369	151	16 February 1966
J2-369R1	--	N/A
J2-369R2	--	N/A
J2-369R3	--	N/A
J2-369R4	--	N/A
J2-370	150, 280, 281	6 August 1965
J2-370R1	--	N/A
J2-370R2	--	N/A
J2-371	70	N/A
J2-372	134	N/A
J2-376	135	N/A
J2-380	136	N/A
J2-382	136	6 August 1965
J2-383	158	N/A
J2-383R1	--	N/A
J2-387	149, 154	25 October 1965
J2-387R1	--	N/A
J2-387R2	--	N/A
J2-387R3	--	N/A
J2-387R4	--	N/A
J2-388	166	N/A
J2-389	144	N/A
J2-389R1	--	N/A
J2-389R2	--	N/A
J2-390	143	N/A
J2-390R1	--	N/A
J2-391	88	N/A
J2-391R1	--	N/A
J2-394	148	6 August 1965
J2-394R1	--	N/A
J2-395	146	25 October 1965
J2-395R1	--	N/A
J2-397	156	N/A
J2-398	182	N/A
J2-398R1	--	N/A
J2-399	163, 167, 202	16 February 1966
J2-399R1	--	N/A
J2-399R2	--	N/A
J2-399R3	--	N/A
J2-399R4	--	N/A
J2-401	152	N/A
J2-403	157	N/A
J2-403R1	--	N/A
J2-403R2	--	N/A
J2-404	88	N/A
J2-405	237	17 August 1966
J2-405R1	--	N/A
J2-405R2	--	N/A
J2-407	88	N/A
J2-408	155, 227	6 August 1965
J2-408R1	--	N/A
J2-409	166	N/A
J2-409R1	--	N/A
J2-409R2	--	N/A
J2-410	160	6 August 1965
J2-410R1	--	N/A
J2-412	159	N/A
J2-413	161	N/A
J2-413R1	--	N/A
J2-414	174	25 October 1965
J2-414R1	--	N/A
J2-414R2	--	N/A
J2-415	170, 199, 200	16 February 1966
J2-415R1	--	N/A
J2-415R2	--	N/A
J2-415R3	339	N/A
J2-416	164, 165	N/A
J2-416R1	--	N/A
J2-417	173	N/A
J2-419	168, 169	N/A
J2-421	172	6 August 1965
J2-421R1	--	N/A
J2-422	171	16 February 1966
J2-423	--	N/A
J2-426	185	16 February 1966

Figure 3. Configuration Changes--Manual Effectivity (Sheet 3 of 6)

Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-428	194	16 February 1966
J2-429	185	16 February 1966
J2-430	172	16 February 1966
J2-430R1	--	N/A
J2-430R2	--	N/A
J2-430R3	--	N/A
J2-431	177	25 October 1965
J2-431R1	--	N/A
J2-431R2	--	N/A
J2-432	176	N/A
J2-433	178	25 October 1965
J2-434	180,181	25 October 1965
J2-435	179	16 February 1966
J2-435R1	--	N/A
J2-437	192,246	18 May 1967
J2-437R1	--	N/A
J2-437R2	--	N/A
J2-438	185	N/A
J2-440	201	25 October 1965
J2-445	172	N/A
J2-449	183	25 October 1965
J2-449R1	--	N/A
J2-451	172,206	17 August 1966
J2-452	184	16 February 1966
J2-455	188,198	16 February 1966
J2-455R1	--	N/A
J2-455R2	--	N/A
J2-455R3	--	N/A
J2-458	191	16 February 1966
J2-458R1	--	N/A
J2-459	205	16 February 1966
J2-459R1	--	N/A
J2-459R2	--	N/A
J2-461	204	17 August 1966
J2-461R1	--	N/A
J2-461R2	--	N/A
J2-463	189	16 February 1966
J2-465	190,334	16 February 1966
J2-465R1	--	N/A
J2-466	239,310	N/A
J2-466R1	--	N/A
J2-466R2	--	N/A
J2-467	212	N/A
J2-468	172	3 May 1966
J2-468R1	--	N/A
J2-469	195	N/A
J2-469R1	--	N/A
J2-470	211,319	3 May 1966
J2-470R1	--	N/A
J2-471	212,228	16 February 1966
J2-471R1	--	N/A
J2-471R2	--	N/A
J2-472	193	3 May 1966
J2-474	215,231,245	3 May 1966
J2-474R1	--	N/A
J2-474R2	--	N/A
J2-474R3	--	N/A
J2-474R4	--	N/A
J2-474R5	--	N/A
J2-475	--	3 May 1966
J2-475R1	--	N/A
J2-475R2	--	N/A
J2-476	196	N/A
J2-476R1	--	N/A
J2-476R2	--	N/A
J2-476R3	--	N/A
J2-477	239,310	N/A
J2-477R1	--	N/A
J2-477R2	--	N/A
J2-479	206,232	N/A
J2-479R1	--	N/A
J2-479R2	--	N/A
J2-479R3	--	N/A
J2-481	217	N/A
J2-482	222	N/A
J2-482R1	--	N/A
J2-483	224,225,292	N/A
J2-483R1	--	N/A
J2-483R2	--	N/A
J2-483R3	--	N/A
J2-483R4	--	N/A
J2-485	--	N/A
J2-488	208	N/A
J2-488R1	--	N/A
J2-489	185	N/A
J2-489R1	--	N/A
J2-489R2	--	N/A
J2-492	223	18 May 1967
J2-492R1	--	N/A
J2-492R2	--	N/A
J2-492R3	--	N/A
J2-493	185	N/A
J2-494	210	N/A
J2-495	207	N/A
J2-496	203	N/A
J2-497	213	N/A
J2-497R1	--	N/A
J2-499	--	N/A
J2-499R2	--	N/A
J2-500	209	3 May 1966

Figure 3. Configuration Changes--Manual Effectivity (Sheet 4 of 6)

Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-501	--	3 May 1966
J2-501R1	--	N/A
J2-501R2	--	N/A
J2-505	214	3 May 1966
J2-507	226	17 August 1966
J2-507R1	--	N/A
J2-510	218	N/A
J2-511	219	N/A
J2-511R1	--	N/A
J2-513	221	3 May 1966
J2-513R1	--	N/A
J2-514	--	N/A
J2-522	--	N/A
J2-522R1	--	N/A
J2-522R2	--	N/A
J2-523	233	17 August 1966
J2-524	229	N/A
J2-525	234	18 May 1967
J2-525R1	--	N/A
J2-527	238,248 250,290	18 May 1967
J2-527R1	--	N/A
J2-527R2	--	N/A
J2-527R3	341	N/A
J2-528	--	N/A
J2-528R1	--	N/A
J2-529	230	N/A
J2-531	243	N/A
J2-532	270	N/A
J2-532R1	--	N/A
J2-538	244	18 May 1967
J2-538R1	--	N/A
J2-540	240	N/A
J2-541	--	N/A
J2-541R1	--	N/A
J2-542	242	N/A
J2-544	236	N/A
J2-545	235	N/A
J2-546	243	N/A
J2-546R1	--	N/A
J2-547	241	N/A
J2-547R1	--	N/A
J2-547R2	--	N/A
J2-548	237	N/A
J2-549	247	18 May 1967
J2-550	262	10 July 1968
J2-551	276,277	N/A
J2-551R1	--	N/A
J2-552	251,252	N/A
J2-553	254	18 May 1967
J2-553R1	347	18 June 1969
J2-555	264	N/A
J2-556	--	N/A
J2-557	249	N/A
J2-558	258,261,321	N/A
J2-558R1	--	N/A
J2-559	--	N/A
J2-560	--	N/A
J2-561	273	N/A
J2-564	253	N/A
J2-566	243	N/A
J2-566R1	--	N/A
J2-567	275	29 November 1967
J2-567R1	--	N/A
J2-568	271	29 November 1967
J2-570	294	N/A
J2-571	239	N/A
J2-571R1	--	N/A
J2-575	256,267,278	18 May 1967
J2-575R1	--	N/A
J2-575R2	--	N/A
J2-575R3	--	N/A
J2-575R4	--	N/A
J2-575R5	--	N/A
J2-576	--	N/A
J2-577	--	N/A
J2-577R1	--	N/A
J2-577R2	--	N/A
J2-577R3	--	N/A
J2-580	--	N/A
J2-581	257,318	N/A
J2-581R1	--	N/A
J2-581R2	--	N/A
J2-581R3	--	N/A
J2-582	259	N/A
J2-587	291	N/A
J2-588	263,274	20 September 1967
J2-588R1	--	N/A
J2-588R2	--	N/A
J2-588R3	355	18 June 1969
J2-589	--	N/A
J2-590	260	N/A
J2-590R1	--	N/A
J2-590R2	--	N/A
J2-590R3	--	N/A
J2-590R5	--	18 June 1969
J2-592	272	20 September 1967
J2-594	268,269,279, 282,296,313, 314,315	20 September 1967

Figure 3. Configuration Changes--Manual Effectivity (Sheet 5 of 6)

Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-594R1	--	N/A
J2-594R2	--	N/A
J2-594R3	--	N/A
J2-598	266	N/A
J2-599	265	N/A
J2-599R1	--	N/A
J2-599R2	--	N/A
J2-600	239	N/A
J2-601	283	29 November 1967
J2-601R1	--	N/A
J2-602	284,285	N/A
J2-602R1	--	N/A
J2-603	286	N/A
J2-603R1	--	N/A
J2-603R2	--	N/A
J2-604	--	N/A
J2-605	287	29 November 1967
J2-606	324	10 July 1968
J2-606R1	--	N/A
J2-607	288,289,290,297,298,299,305,306,307,308,309,352	N/A
J2-607R1	--	N/A
J2-607R2	--	N/A
J2-608	300	N/A
J2-612	293	29 November 1967
J2-612R1	--	N/A
J2-613	--	N/A
J2-616	303,304	29 November 1967
J2-618	270	N/A
J2-620	295,301,302,322,323	29 November 1967
J2-620R1	--	N/A
J2-620R2	--	N/A
J2-620R3	--	N/A
J2-621	311,312	N/A
J2-624	316,317,320	10 July 1968
J2-624R1	342,351	18 June 1969
J2-624R2	--	N/A
J2-627	--	N/A
J2-631	325	N/A
J2-632	--	N/A
J2-633	340,349,350	18 June 1969
J2-634	--	N/A
J2-636	333	N/A
J2-636R1	--	N/A
J2-637	335	18 June 1969
J2-640	336	N/A
J2-640R1	--	N/A

Approved ECP Number	MD Number	Incorporated in Manual Dated
J2-641	348	N/A
J2-642	--	18 June 1969
J2-643	327,328,329,330,331,332,344,345	18 June 1969
J2-643R1	--	18 June 1969
J2-643R2	--	18 June 1969
J2-645	--	N/A
J2-646	337	N/A
J2-647	343	N/A
J2-647R1	--	N/A
J2-649	--	18 June 1969
J2-650	--	18 June 1969
J2-651	--	N/A
J2-652	--	18 June 1969
J2-653	--	4 December 1969
J2-654	346	N/A
J2-655	--	18 June 1969
J2-656	354	N/A
J2-657	353	N/A
J2-657R1	--	N/A
J2-657R2	--	N/A
J2-659	358	N/A
J2-662	360	N/A
J2-666	359	N/A
J2-666R1	--	N/A
J2-666R3	--	4 December 1969
J2-668	361	18 June 1969
J2-671	--	4 December 1969
J2-675	362	N/A
J2-689	365,366	25 May 1971
J2-689R1	--	N/A
J2-689R2	371	25 May 1971
J2-689R3	--	N/A
J2-694	363	N/A
J2-694R2	363,373,374	N/A
J2-695	364	7 May 1970
J2-697	367,368	N/A
J2-700	370	N/A
J2-704	372	22 February 1971
J2-708R1	380,381	18 October 1972
J2-711	376	N/A
J2-714	377,378,379	N/A
J2-717	383,384	18 October 1972

Figure 3. Configuration Changes--Manual Effectivity (Sheet 6 of 6)

4. ABBREVIATIONS.

The following abbreviations appear throughout this manual:

ASI	Augmented spark igniter
ECA	Electrical control assembly
FI	Flight instrumentation
GG	Gas generator
HB	Huntington Beach (McDonnell-Douglas Corporation)
Hz	Hertz (frequency in cycles per second)
KSC	Kennedy Space Center
M/S	Mainstage
MFV	Main fuel valve
mm Hg	Millimeters of mercury (vacuum)
MOV	Main oxidizer valve
MRCV	Mixture ratio control valve
MTF	Mississippi Test Facility (NASA)
MR	Mixture Ratio
NASA	National Aeronautics and Space Administration
NPSH	Net positive suction head
OTBV	Oxidizer turbine bypass valve
Pc	Chamber pressure
PU	Propellant utilization
SAC/MDAC	Sacramento Test Site (McDonnell-Douglas Corporation)
SB	Seal Beach (Space Division)
SIC	Spark igniter cable
STDV	Start Tank discharge valve
VAB	Vertical Assembly Building (KSC)
VSC	Vibration safety cutoff

SECTION I

DESCRIPTION AND OPERATION

1-1. SCOPE. This section contains general description of the J-2 rocket engine and a detailed description of each subsystem and engine component. Engine operation is described from engine start through cutoff.

1-2. J-2 ROCKET ENGINE.

1-3. The J-2 rocket engine (figure 1-1) is a high-performance, multiple-restart engine that uses liquid oxygen for oxidizer and liquid hydrogen for fuel. Each propellant is pumped into the thrust chamber by separate gas-turbine-driven, direct-drive turbopumps. The two turbopumps are powered in series by a single gas generator that uses the same propellants as the thrust chamber. The thrust chamber is tubular-walled and is regeneratively cooled by circulating fuel through the tubes before the fuel is injected into the combustion area. The engine has a refillable start tank from which pressurized gaseous hydrogen is routed to the turbopump turbines for starting the engine. This feature, combined with the augmented spark ignition system, makes the J-2 a multistart engine. Average performance parameters and major components weights for the engine are in figure 1-2.

1-4. J-2 ENGINE APPLICATION AND RELATED CONFIGURATION.

1-5. The J-2 rocket engine was developed to provide the power for the SIVB stage of the Saturn IB vehicle and for the SII and SIVB stages of the Saturn V vehicle. (See figure 1-3.)

1-6. The SII stage is propelled by a cluster of five J-2 engines, four outboard engines and one inboard engine. Because only a single engine start is required for SII stage application, the engines are modified to delete the engine restart capability by blocking off the start tank refill lines. The inboard and outboard engines are basically identical, except that the inboard engine has stage-provided inlet ducts, the hydrogen tank pressurization tapoff on the thrust chamber fuel injection manifold is not used, and the stage-provided hydraulic pump is not installed on the oxidizer turbopump accessory drive pad. Each engine is attached to the stage structure by the gimbal assembly. The inboard engine is stabilized by fixed struts connected to the thrust chamber gimbal actuator attach points. The outboard engines have stage-provided gimbal actuators that gimbal the engines to provide pitch, yaw, and roll movements to the vehicle. Hydraulic pressure for operation of the gimbal actuators is supplied by a stage-provided hydraulic pump mounted on the accessory drive pad located on the turbine exhaust manifold of the oxidizer turbopump.

1-7. The SIVB stage is propelled by one J-2 engine. The engine used in the Saturn IB, SIVB stage and the engine used in the Saturn V, SIVB stage are basically identical, except that the engine used in the Saturn IB, SIVB stage is modified to delete the engine restart capability by blocking off the start tank refill lines. The SIVB stage routes stage-supplied helium instead of engine-supplied oxygen through the engine heat exchanger for oxidizer tank pressurization. The heat exchanger antiflood check valve and the oxidizer supply line are removed from the engine and a blanking plate is installed on the high-pressure duct. The engine is attached to the stage structure by the gimbal assembly. Stage-provided gimbal actuators are connected to attach points on the thrust chamber. The actuators gimbal the engine to provide pitch and yaw movements to the vehicle.

1-8. ENGINE PHYSICAL DESCRIPTION.

1-9. The J-2 rocket engine (figure 1-1) is within an envelope 80.75 inches in diameter and 133 inches long and weighs approximately 3,492 pounds dry. Thrust vector is achieved by gimbaling the entire engine. The gimbal is installed at the center of the thrust chamber injector dome, and gimbal actuator attach points are located on the thrust chamber body. The rocket engine comprises the propellant feed system, gas generating system, start system, ignition system, control system, purge system, and the flight instrumentation system. (See figure 1-4.)

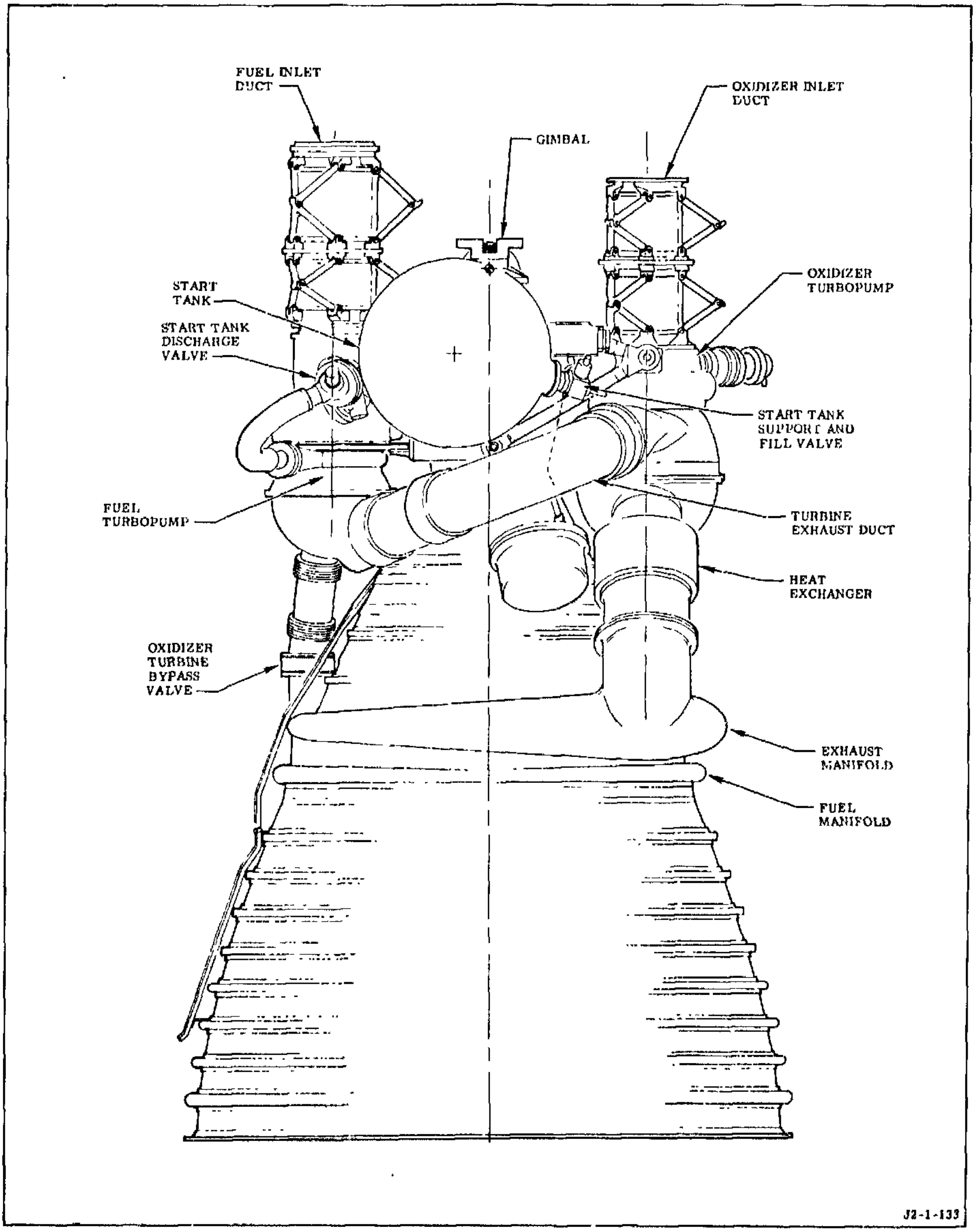

Figure 1-1. J-2 Rocket Engine (Sheet 1 of 2)

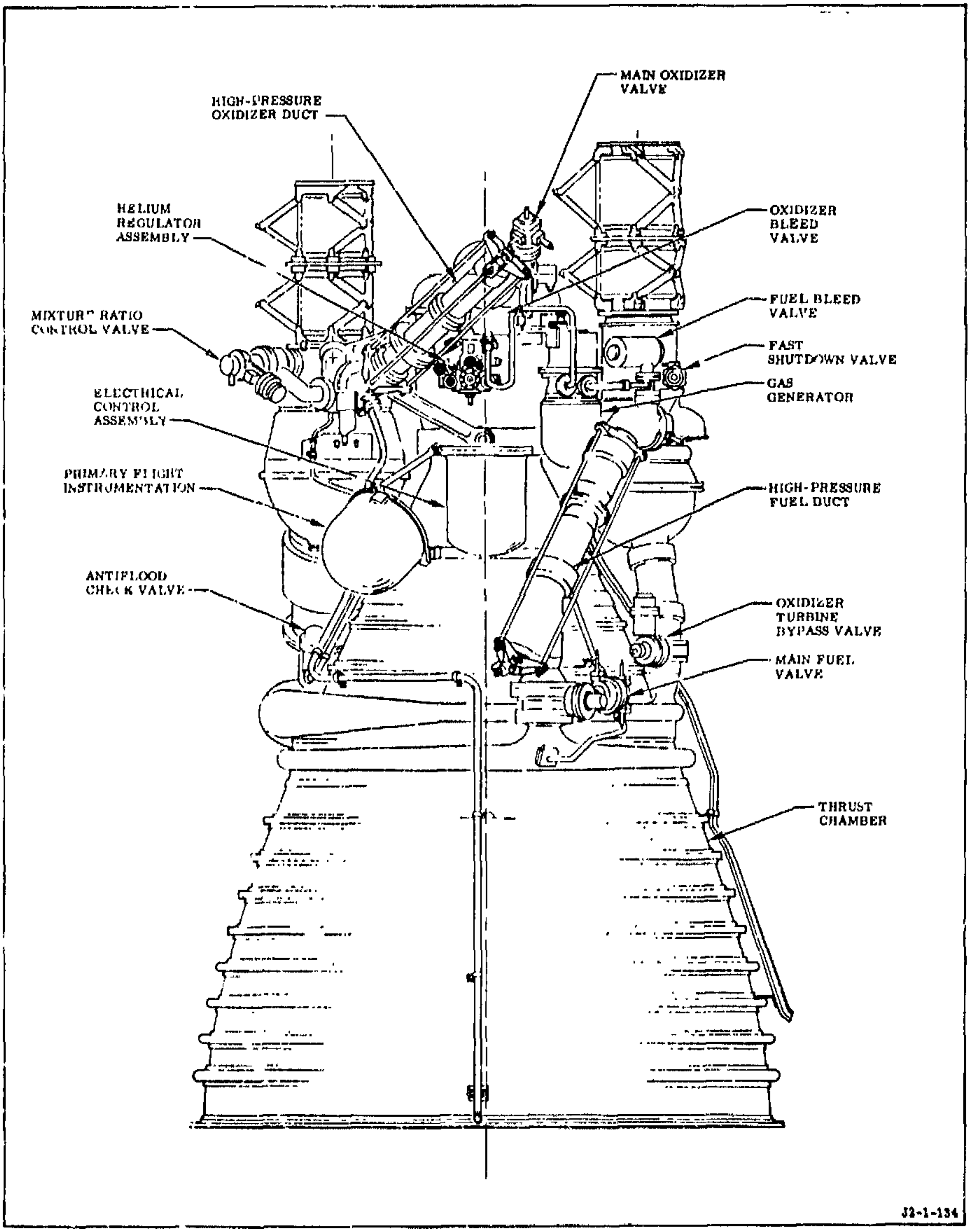

Figure 1-1. J-2 Rocket Engine (Sheet 2 of 2)

Average Performance Parameters (230K Engines)

Thrust (Altitude)	230,000 pounds
Specific Impulse	425 seconds
Oxidizer Flowrate (LO_2)	468 lb/sec - 2,365 gpm
Fuel Flowrate (LH_2)	84 lb/sec - 8,587 gpm
Mixture Ratio	5.5:1 O/F
Fuel Pump Speed	27,167 rpm
Oxidizer Pump Speed	8,698 rpm
Fuel Pump Outlet Pressure	1,251 psia
Oxidizer Pump Outlet Pressure	1,108 psia
Thrust Chamber Pressure (Injector)	780 psia
Gas Generator Pressure (Injector)	682 psia

Major Components Weights	Weight (lb)
Gimbal Bearing (Without Boot and Attached Hardware)	77
Thrust Chamber Injector Dome	213
Thrust Chamber Body	891
Fuel Turbopump	418
Oxidizer Turbopump	304
Fuel Turbine Exhaust Duct	73
Heat Exchanger Duct	104
Fuel Turbopump Inlet Duct (Haynes 25 (L 605) Bellows)	136
Fuel Turbopump Inlet Duct (Inco 718 Bellows)	111
Oxidizer Turbopump Inlet Duct (Haynes 25 (L 605) Bellows)	121
Oxidizer Turbopump Inlet Duct (Inco 718 Bellows)	94
Integral Hydrogen-Helium Start Tank (Insulated)	89
Main Oxidizer Valve	32
Main Fuel Valve	24

Major Components Weights	Weight (lb)
Gas Generator Control Valve	21
Fuel Bleed Valve	12
Oxidizer Bleed Valve	12
Start Tank Discharge Valve	28
Oxidizer Turbine Bypass Valve	19
Mixture Ratio Control Valve	25
Start Tank Discharge Valve Hose	17
High-Pressure Oxidizer Duct (With Flowmeter)	64
High-Pressure Fuel Duct (With Flowmeter and Insulated)	74
Primary Instrumentation Package	33
Auxiliary Instrumentation Package	29
Electrical Control Assembly	58
Helium Regulator Assembly (Pneumatic Control Package)	20

Figure 1-2. Average Engine Performance Parameters and Major Components Weights

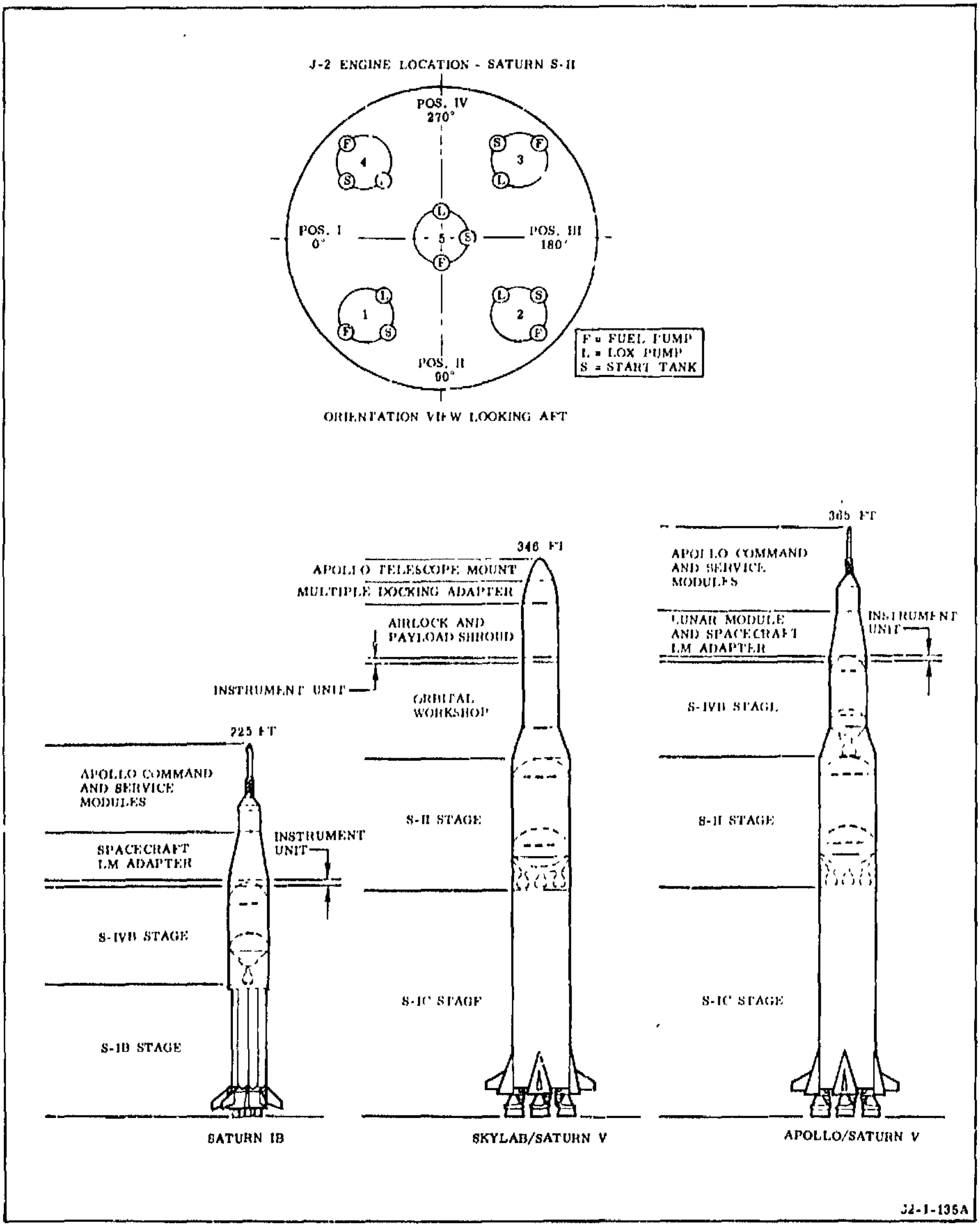

Figure 1-3. J-2 Engine Application

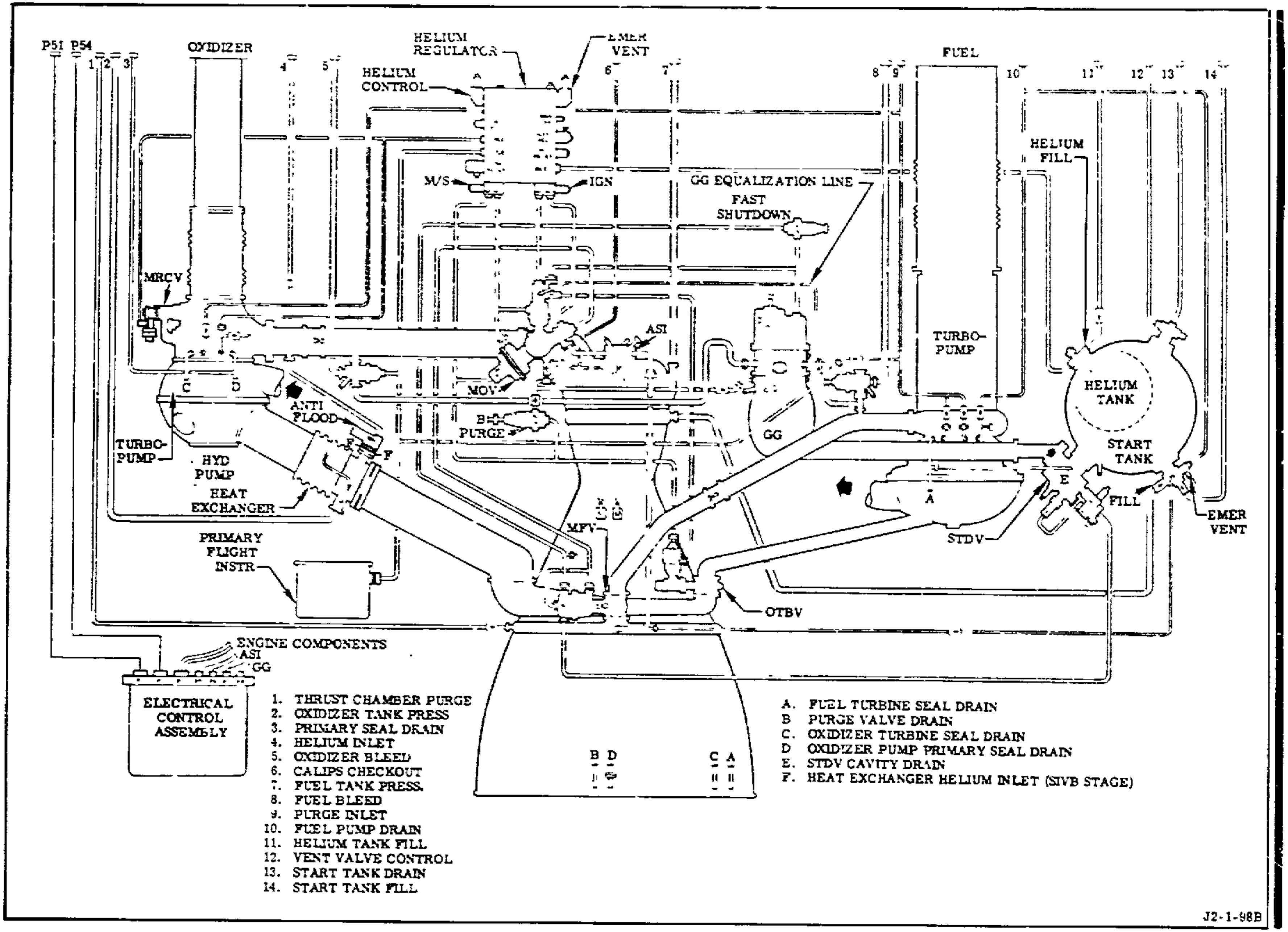

Figure 1-4. J-2 Engine Schematic

1-10. PROPELLANT FEED SYSTEM DESCRIPTION.

1-11. The propellant feed system transfers and controls the oxidizer and fuel from the stage to the thrust chamber and gas generator combustion zones. The system consists of a thrust chamber assembly, oxidizer turbopump, fuel turbopump, main oxidizer valve, main fuel valve, oxidizer and fuel bleed valves, propellant inlet ducts, propellant high-pressure ducts, and a mixture ratio control valve.

1-12. THRUST CHAMBER ASSEMBLY.

1-13. The thrust chamber assembly receives liquid propellants under turbopump pressure, gasifies, mixes, and burns the propellants, and imparts a high velocity to the expelled combustion gases to produce thrust for vehicle propulsion.

1-14. The thrust chamber assembly consists of a thrust chamber body, an injector assembly, and a gimbal bearing assembly. The integral dome/injector assembly is bolted to the body. The mating surfaces of the injector assembly and thrust chamber body are sealed at the inner diameter by a hollow K-Monel O-ring seal and at the outer diameter by a pressure-actuated Naflex seal at the bolted flange. The gimbal bearing assembly is bolted to four support posts machined into the forward end of the injector assembly.

1-15. THRUST CHAMBER BODY. The thrust chamber body contains a combustion chamber for burning the propellants, a narrowing throat section, and a 27.5:1 expansion nozzle section through which combustion gases are expelled at the supersonic velocity necessary to produce the desired thrust.

1-16. The thrust chamber body (figure 1-5) is 107 inches long and has an inside diameter of 18.3 inches at the combustion chamber, 14.7 inches at the throat, and 77 inches at the exit ring. The thrust chamber body is a tubular-walled, regeneratively fuel-cooled, bell-shaped chamber constructed of formed stainless steel tubes consisting of 180 short (down) tubes and 360 long (up) tubes. The tubes are furnace-brazed together and are supported by bands around the tubes for external stiffening. The thrust chamber body has three manifolds. The forward fuel manifold is welded to the top of the thrust chamber body and has a flange for the attachment of the injector. The manifold receives hydrogen from the chamber up tubes, distributes the hydrogen to the fuel section of the injector, and supplies gaseous hydrogen for pressurizing the stage fuel tank and for refilling the engine start tank. The fuel inlet manifold is welded around the middle of the chamber at the plane where the short (down) tubes start. The manifold has a flange for the attachment of the main fuel valve. Fuel enters the manifold through the main fuel valve and is distributed to the 180 short (down) tubes, which ends are welded to the manifold. The fuel inlet manifold also has an augmented spark igniter fuel supply port and a fuel jacket purge inlet port. The exhaust manifold is a tapered manifold welded around the chamber just above the fuel inlet manifold. The manifold has two inlet flanges 180 degrees apart; one inlet is connected to the oxidizer turbine exhaust duct and the other to the oxidizer turbine bypass valve. The manifold outlet is through openings between the long (up) tubes (cat-eyes) along the inside diameter of the thrust chamber.

1-17. THRUST CHAMBER INJECTOR. The thrust chamber injector (figure 1-6) is a fuel-face-cooled, concentric element injector that mixes and distributes the propellants into the combustion chamber in a manner to produce the most efficient combustion. The injector is approximately seven inches in length and 22 inches in diameter. The injector is a welded, one-piece injector/dome unit containing 614 oxidizer feed posts, an equal number of fuel sleeves, and a porous metallic faceplate. The oxidizer posts are electrically discharge machined from the nickel alloy injector plate die forging, and direct the oxidizer from the dome to the combustion chamber. The fuel sleeves are threaded to the oxidizer posts, and retain the faceplate in position. The sleeves have four radial fuel inlet holes ported to the gap between the oxidizer posts and sleeves which direct the fuel from the fuel manifold to the combustion chamber. The porous faceplate is transpiration cooled by fuel from the fuel manifold and contains a row of 253 fuel orifices near its outer diameter to film cool the walls of the combustion chamber.

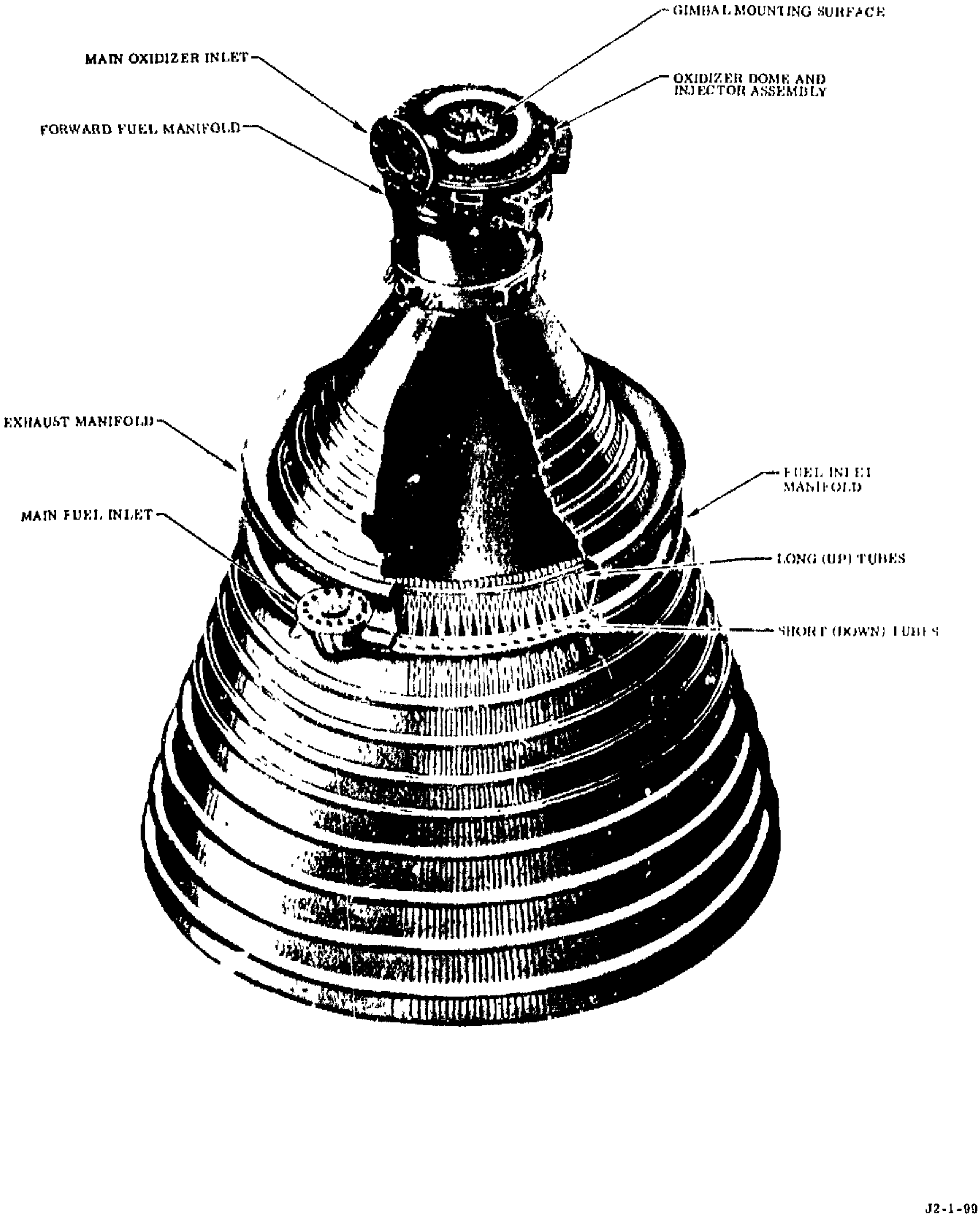

Figure 1-5. Thrust Chamber

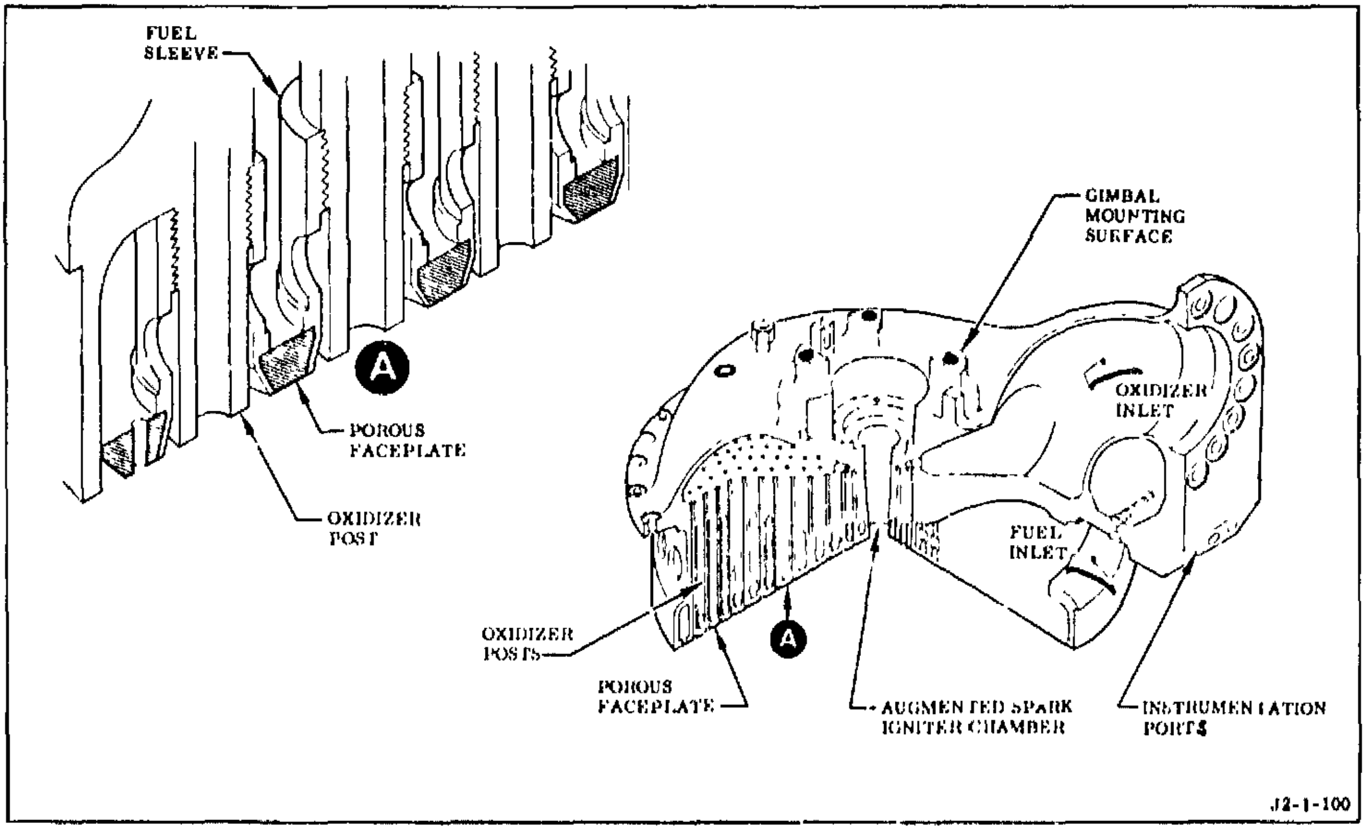

Figure 1-6. Thrust Chamber Injector

1-18. GIMBAL.

1-19. The gimbal bearing assembly (figure 1-7) is approximately ten inches in diameter and six inches high and is mounted on the thrust chamber and is attached to the stage frame. The gimbal is used to support the engine, transmit thrust to the stage, and permit the engine to be rotated about its x- and z-axes to enable the vehicle to change angular direction of velocity for course correction. The gimbal is essentially a universal joint that consists of a spherical bearing, coated with a Teflon-fiberglass composition (fabroid), and is held in a spherical socket. The fabroid provides a dry, low-friction-bearing surface. The gimbal consists of a misalinement plate, a body, a shaft, and a seat. The spherical section of the shaft mates with the body, and the spherical section of the body mates with the seat to form the universal joint. The misalinement plate and body bolt to the thrust chamber injector, and the shaft fits into a recess of the body and is secured by two retainers. The seat bolts to the stage and is indexed by a keyway and two keys. Two adjustment bolts allow the misalinement plate to be laterally repositioned to the injector and the body to be laterally repositioned relative to the misalinement plate.

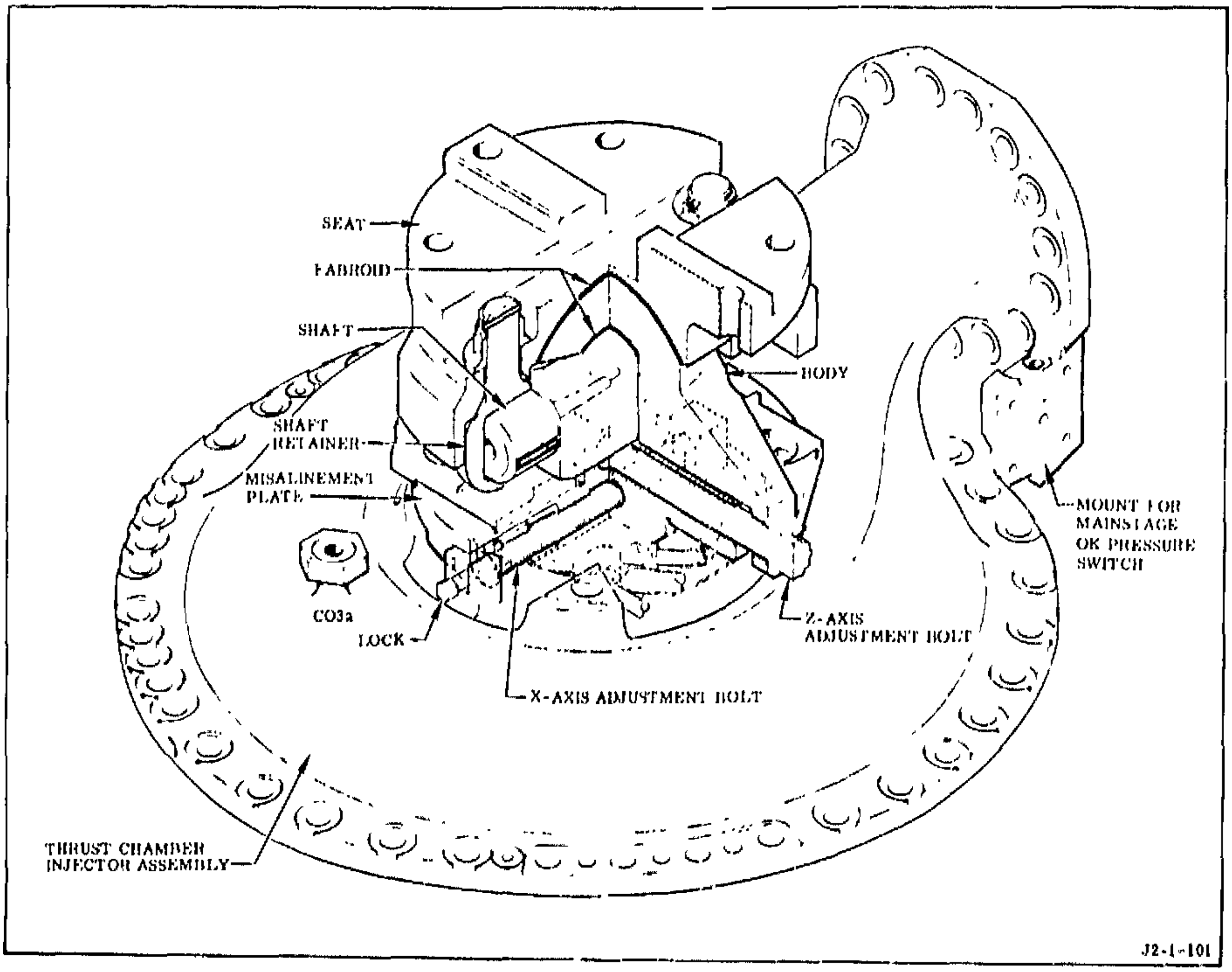

Figure 1-7. Gimbal

1-20. OXIDIZER TURBOPUMP.

1-21. The oxidizer turbopump (figure 1-8) is a single-stage, centrifugal-type pump powered by a direct-drive, two-stage, gas-driven turbine. The principal parts of the oxidizer turbopump are a pump shaft, an inducer, an impeller, a volute and two turbine wheels. Carbon seals, augmented by a dynamic helium purge, contain the oxidizer and provide a barrier between the oxidizer and the hot gas. The pump is within a basic envelope 21 inches in diameter and 18 inches in length.

1-22. The pump shaft is a hollow, chromium-plated, nickel alloy shaft, supported by two liquid-oxygen-cooled bearings. The inducer and impeller are spline connected to the forward end of the shaft, and the turbine wheels are connected through curvic couplings and bolts to the other end. An internally splined adapter, bolted to the second-stage turbine wheel, provides the power takeoff to drive a stage-provided hydraulic pump. The volute houses the shaft, inducer and impeller, and has two flanges on which the mixture ratio control valve is mounted. One flange is ported to the discharge side of the pump, and the other is ported by internal passages to the inlet side of the impeller. The volute supports the turbine manifold by 33 radially installed pins which permit movement of the manifold and volute section caused by thermal expansion and contraction. The carbon seals consist of a bellows loaded, face-riding, primary seal that contains the liquid oxygen at the No. 2 bearing, a similar type turbine seal located forward of the first-stage turbine wheel to contain the hot gas in the turbine section, and a carbon segmented intermediate seal located between the primary and turbine seals. The intermediate seal is purged with helium during engine operation to further isolate the oxidizer from the hot gas.

1-23. The driving force for operating the oxidizer turbopump is provided by the two-stage turbine which is driven by hot gas that has previously passed through the fuel turbopump turbine from the gas generator. The turbines of the oxidizer and fuel turbopumps are connected in-series by exhaust ducting that directs the discharged exhaust gas from the fuel turbopump turbine to the inlet of the oxidizer turbopump turbine manifold. The manifold routes the hot gas to the turbine nozzle, which increases the velocity of the hot gas and directs it to the turbine blades of the first-stage turbine wheel, from where the gas is directed by the stator blades to the second-stage turbine wheel. After leaving the turbine the gas is routed through the heat exchanger to the exhaust manifold and then overboard through the thrust chamber. Power from the turbine is transmitted to the impeller and inducer by the pump shaft. Liquid oxygen enters the pump at stage oxidizer tank pressure, and the inducer increases the oxidizer pressure, to prevent cavitation, and directs the oxygen to the inlet of the impeller. The impeller increases the velocity of the oxygen and discharges it into the volute. The volute converts the kinetic energy of fluid velocity to potential energy of fluid pressure. The liquid oxygen is then directed from the volute to the high-pressure duct.

1-24. FUEL TURBOPUMP.

1-25. The fuel turbopump (figure 1-9) is an axial flow pumping unit, powered by a direct-drive, two-stage, gas-driven turbine. The principal parts of the fuel turbopump are a one-piece, seven-stage rotor, a three-section stator assembly, a volute, an inducer, two turbine wheels, and the necessary seals to contain the hydrogen and provide a barrier between the hydrogen and the hot gas. The pump is within a basic envelope 18 inches in diameter and 30 inches in length.

1-26. The one-piece rotor contains seven rows of blades machined into the outer periphery and is encased by the stator assembly which has six rows of stator vanes at its inner periphery. The rotor is supported by two liquid-hydrogen-cooled ball bearings that are spring-loaded in opposing directions, to maintain the axial position of the rotor during static conditions. During pump operation, the axial position of the rotor is maintained by a self-compensating balance piston, powered by liquid hydrogen bled from the last stage of the rotor. The volute assembly encloses the stator assembly and contains the flanges for attaching the fuel inlet duct and the fuel high-pressure duct. The volute is insulated with polyurethane foam, to aid in maintaining the hydrogen in its liquid state. The inducer is spline-connected to the forward end of the rotor shaft, and the two turbine wheels are mounted

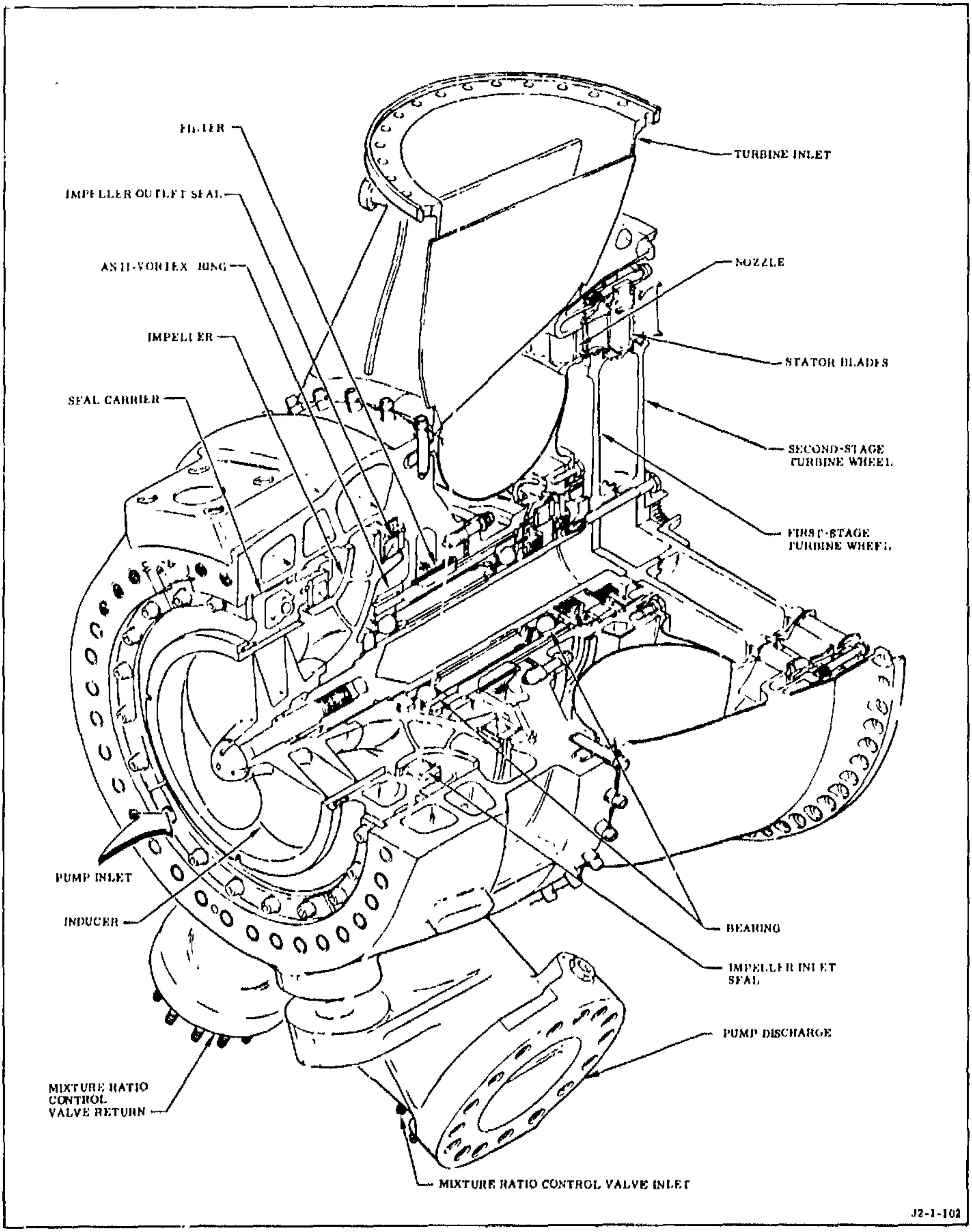

Figure 1-8. Oxidizer Turbopump (Sheet 1 of 2)

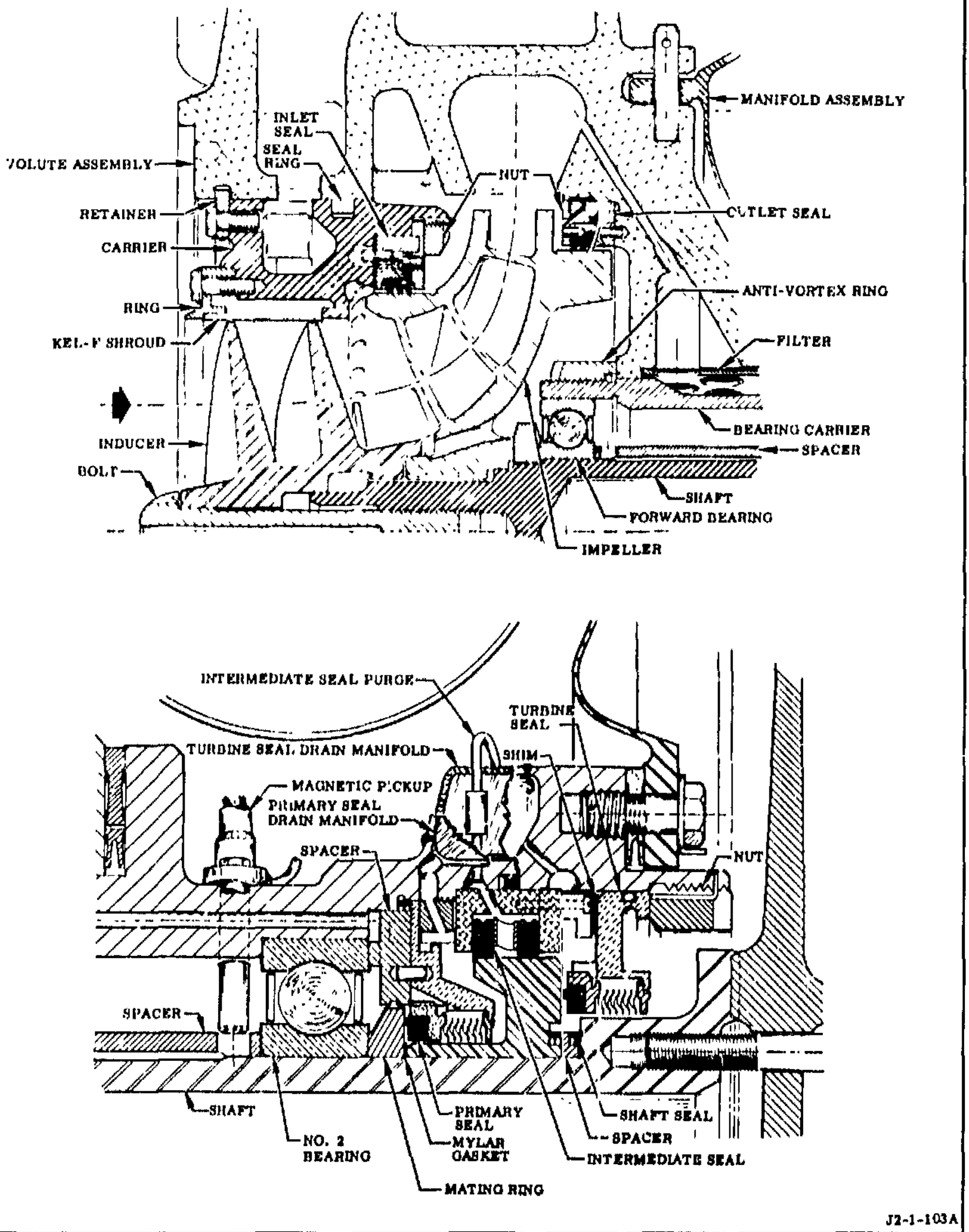

Figure 1-8. Oxidizer Turbopump (Sheet 2 of 2)

on studs at the other end of the rotor shaft. Two face-riding, bellows-loaded seals and one carbon-segmented seal isolate the liquid hydrogen from the turbine section. The face-riding seals consist of the primary seal, located behind the No. 2 bearing, and the secondary seal, located between the primary seal and the turbine seal. The carbon-segmented turbine seal is the seal located nearest the turbine section. The cavities between the primary seal and secondary seal and between the secondary seal and the turbine seal are purged with stage-provided helium to eliminate any moisture before introducing propellants to the engine.

1-27. The driving force for operating the fuel turbopump is provided by the two-stage turbine that is driven by hot gas from the gas generator during engine operation. A manifold with two inlet ports connects the gas generator to the turbine; one inlet receives gas from the start tank for engine starting and the other from the gas generator during engine operation. Gas is routed to the turbine inlet manifold, which distributes the gas to the nozzle. The nozzle increases gas velocity and directs the gas into the first-stage turbine wheel, and the stator blades direct the gas to the second-stage turbine wheel. After leaving the turbine the gas is routed through exhaust ducting to the oxidizer turbopump turbine and the oxidizer turbine bypass valve. Liquid hydrogen enters the pump inlet at stage fuel tank pressure and the inducer increases the hydrogen pressure, to prevent cavitation and permit a lower inlet pressure. The inducer directs the hydrogen through the support vanes into the first-stage blades of the rotor, where compression begins. The hydrogen is then redirected by the first row of stator vanes into the next row of rotor blades. This action is repeated through the seven stages, with each stage contributing to the total pressure buildup. Hydrogen from the final stage is directed through the diffuser vanes within the volute and out into the high-pressure fuel duct.

1-28. MAIN OXIDIZER VALVE.

1-29. The main oxidizer valve (figure 1-10) controls the flow of oxidizer from the oxidizer turbopump to the thrust chamber. The main oxidizer valve is a pneumatically actuated, spring-loaded closed, valve with a butterfly-type gate. The valve is within a basic envelope of 18 inches by 15 inches by 10 inches. The valve has two open positions controlled by separate first- and second-stage actuators. A sequence valve, that is an integral part of the main oxidizer valve, is mechanically opened by the main oxidizer valve first-stage actuator to direct helium pressure to the gas generator control valve open port and to the oxidizer turbine bypass valve close port. When the valve is in the closed position, the sequence valve connects both sides of the gas generator control valve actuator. The second-stage actuator piston shaft is connected to the gate shaft by a link-and-lever which converts the linear movement of the piston shaft to rotary movement of the gate shaft. The first-stage actuator piston shaft contains a roller bearing at one end that contacts the link of the second-stage actuator shaft when the valve is in the closed position. The opening travel of the first-stage actuator, through the cam action of the bearing and link, opens the valve gate 14 degrees, which is the first position of valve opening. A valve position indicator, consisting of a rotary-motion variable resistor and open and close position switches, is connected to the gate shaft, to remotely indicate valve motion and position. The valve gate housing has mounting pads for the installation of the oxidizer injector purge check valve and augmented spark igniter valve.

1-30. For valve opening, helium pressure is simultaneously applied to opening control ports of the first- and second-stage actuators and vented from the closing control port of the second-stage actuator through a thermal-compensating orifice. The thermal-compensating orifice maintains a constant volume venting rate from the second-stage actuator regardless of helium temperature, so that valve timing changes as a result of actuator gas temperature variations are practically eliminated. At three to eight degrees of valve opening travel, the sequence valve opens to direct helium pressure to open the gas generator control valve and close the oxidizer turbine bypass valve. At 14 degrees of valve opening, the first-stage actuator reaches its limit of travel, and the second-stage actuator opens the valve the remaining 76 degrees. Valve closing is accomplished by applying helium pressure to the closing port of the second-stage actuator and venting opening pressure from both actuators. Valve closing is assisted by actuator springs.

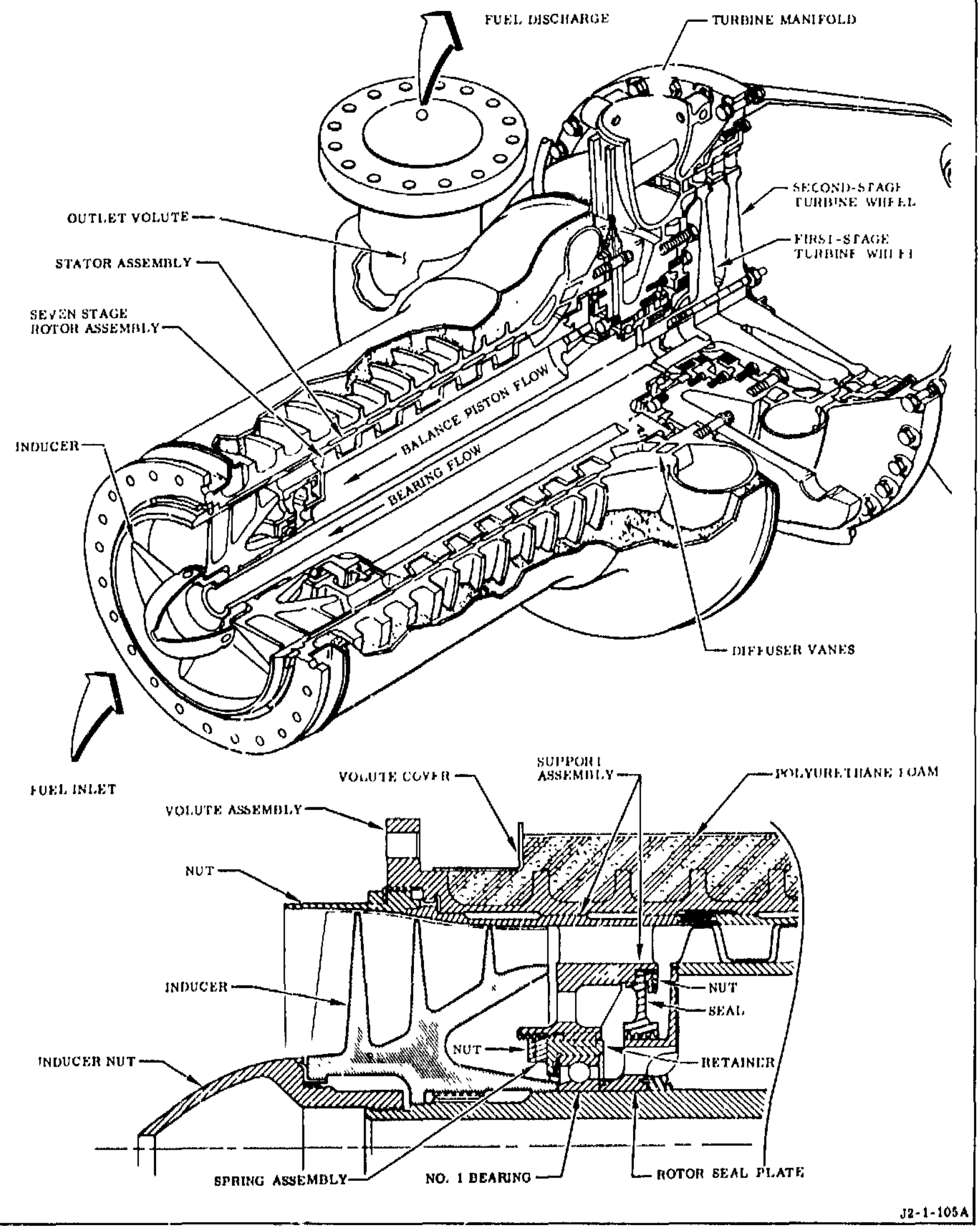

Figure 1-9. Fuel Turbopump (Sheet 1 of 2)

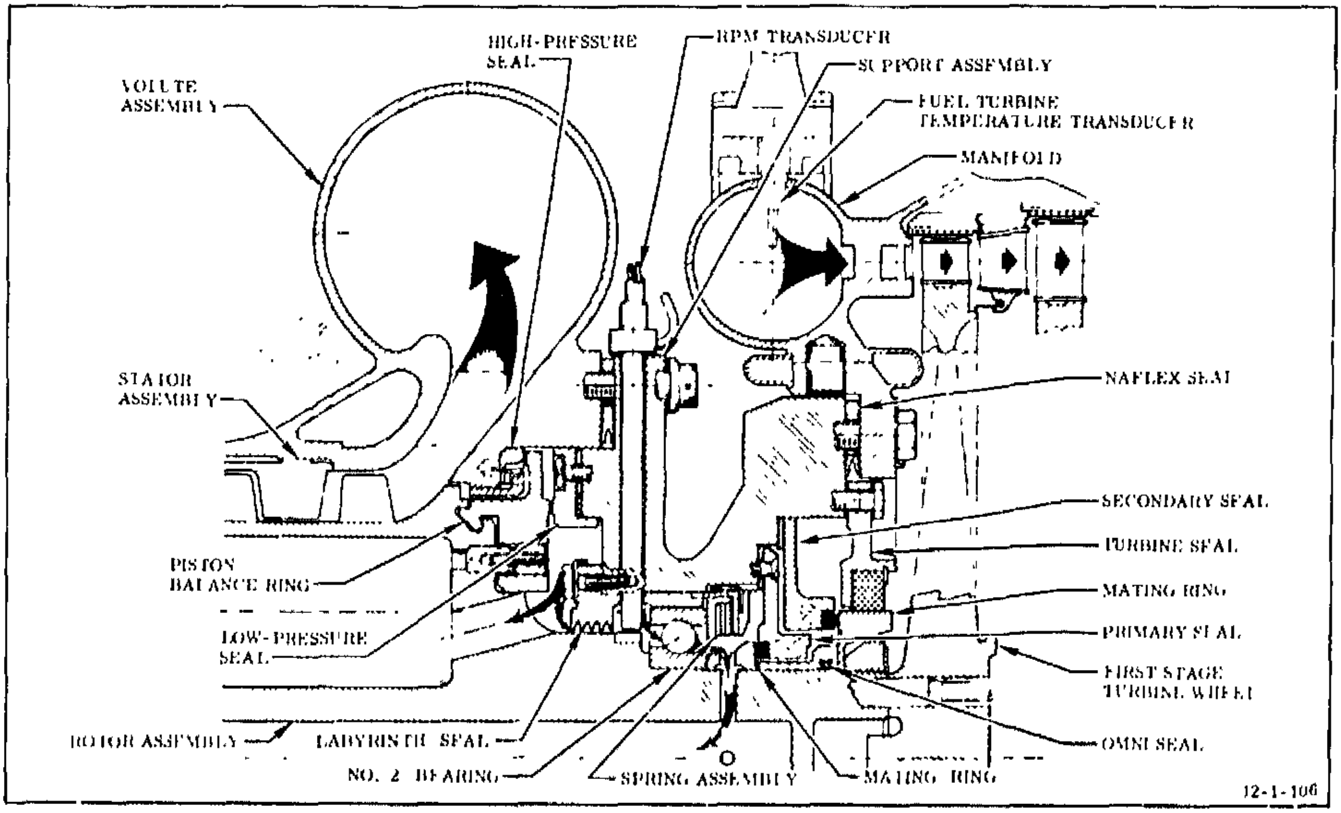

Figure 1-9. Fuel Turbopump (Sheet 2 of 2)

1-31. MAIN FUEL VALVE.

1-32. The main fuel valve (figure 1-11) controls the flow of hydrogen from the fuel turbopump to the thrust chamber. The main fuel valve is a pneumatically actuated, spring-loaded-closed valve with a butterfly-type gate. The valve is within a basic envelope of 18 inches by 15 inches by 10 inches. A sequence valve, that is an integral part of the actuator housing, is opened by the valve actuator piston to admit helium pressure to the start tank discharge valve control valve. The actuator piston shaft is connected to the gate shaft by a link-and-lever which converts the linear movement of the piston shaft to rotary movement of the gate shaft. A valve position indicator, consisting of a rotary-motion variable resistor and open and close position switches, is connected to the gate shaft to remotely indicate valve motion and position.

1-33. The main fuel valve moves from a normally closed position to the open position when helium pressure is applied to the opening control port, and pressure is vented from the closing control port. When the main fuel valve reaches 90-percent open, the actuator piston contacts the sequence valve position. Actuation of the sequence valve connects the sequence in port to the sequence out passage, directing helium pressure to enter the start tank discharge valve control valve. Spring tension and helium pressure applied to the actuator piston close the valve. The main fuel valve opening, closing, and delay times are controlled by an orifice, located at the opening control port.

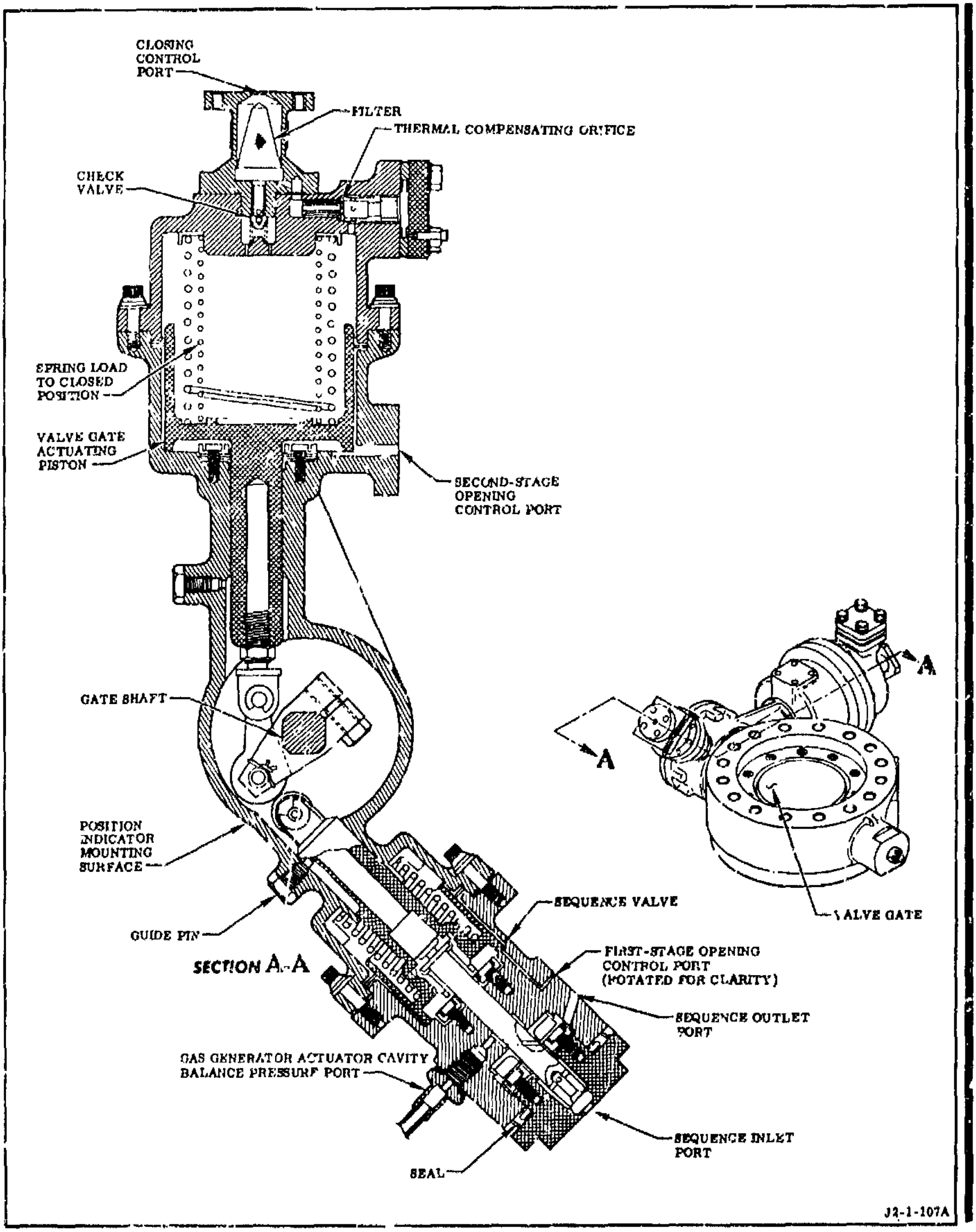

Figure 1-10. Main Oxidizer Valve

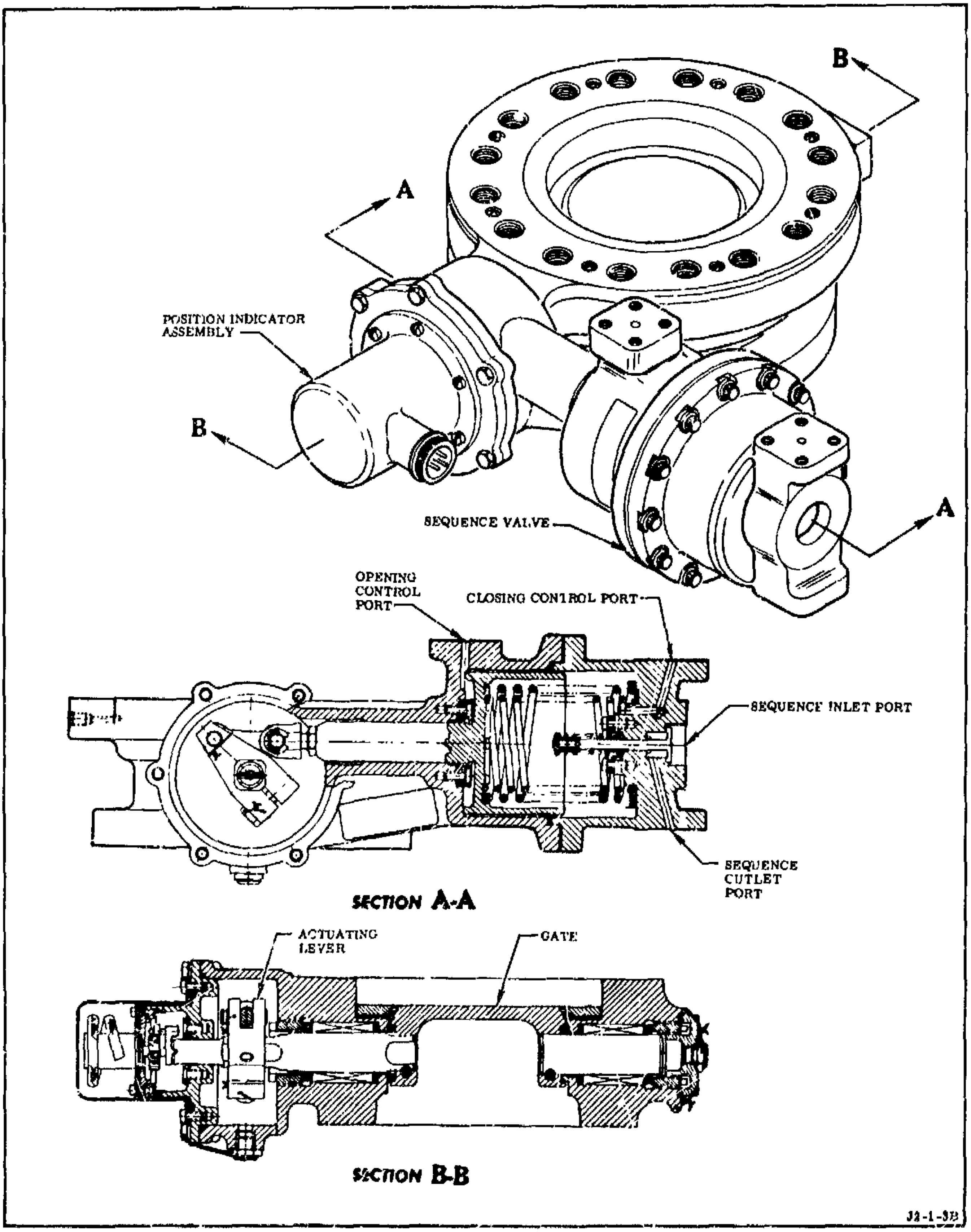

Figure 1-11. Main Fuel Valve

1-34. OXIDIZER AND FUEL BLEED VALVES.

1-35. The oxidizer and fuel bleed valves (figures 1-12 and 1-13) vent propellant gases from the oxidizer and fuel systems during prechill operations, before engine start, and after engine cutoff. The valves, located on the high-pressure ducts, are functionally the same. Each valve is within a basic envelope of six inches by three inches by seven inches. They are poppet-type valves that are bellows-loaded to the open position and pressure-actuated to the close position. The valves have an inner and an outer bellows assembly that acts as springs and seals. The valves incorporate a position switch that indicates when the valve is in the closed position. The inlet and outlet ports are interconnected, with the poppet controlling the bleed port.

1-36. Before engine start, the propellant feed systems are chilled by recirculating fuel and oxidizer from the stage tanks through the engine bleed valves and back to the stage tanks. At engine start, pneumatic pressure is supplied to the closing port of the bleed valves. Pneumatic pressure overcomes the bellows spring force and the bleed pressure on top of the poppet, to actuate the valve to the closed position. As the poppet seats against the bleed port outlet, the position switch sends a signal to indicate that the valve is in the close position. At engine cutoff, pneumatic pressure is removed from the closing port. Bellows tension, aided by propellant pressure remaining inside the inner bellows, opens the valve.

1-37. OXIDIZER AND FUEL INLET DUCTS.

1-38. The oxidizer and fuel inlet ducts (figures 1-14 and 1-15) convey the propellant from the stage to the oxidizer and fuel turbopumps. Each duct has two bellows assemblies, mounted in tandem, and is normally 22.85 inches long, with an inside diameter of eight inches and an outside diameter of 11 inches. The bellows are stabilized by bipod clevis assemblies that allow maximum engine gimbaling without collapsing the bellows. The fuel duct incorporates an internal duct, that results in a double-skinned unit, separated by a gap that provides a vacuum jacket for insulation of the propellant. The two bellows assemblies are bolted together at the center and sealed by the torsional bellows.

1-39. OXIDIZER AND FUEL HIGH-PRESSURE DUCTS.

1-40. The oxidizer and fuel high-pressure ducts (figures 1-16 and 1-17) convey the propellants from the turbopump outlets to the thrust chamber inlets. The fuel duct is approximately 59 inches long with an inside diameter of four inches, and the oxidizer duct is approximately 34 inches long with an inside diameter of four inches. The high-pressure ducts are basically two flanged tubes that are bolted together and support a flowmeter at the mating sections. A bellows section in each section of the ducts allows contraction and expansion. A compensator bellows is located in the protruding portion of the ducts to nullify expansion forces of the other bellows. Three tie rods control expansion and help maintain duct alinement. Each duct has a tapoff for supplying propellants to the gas generator system. The fuel duct is insulated with a layer of polyurethane foam covered with fiberglass.

1-41. MIXTURE RATIO CONTROL VALVE.

1-42. The mixture ratio control valve (figure 1-18) allows the engine to operate at either one of two fixed mixture ratios to achieve maximum vehicle performance. The valve changes mixture ratio by routing a portion of the oxidizer flow from the oxidizer turbopump outlet back to the pump impeller inlet. The valve has an actuator assembly and a gate assembly. The actuator is two-position, electro-pneumatic and is spring-loaded to keep it in the high engine mixture ratio position (valve closed). Pneumatic pressure is directed to the actuator piston by a three-way pneumatic control valve that is energized by a stage signal. The gate assembly consists of a rotating sleeve within a stationary outer sleeve. Each sleeve has three elongated holes; by rotating the inner sleeve (valve gate) the holes are alined or misalined, to control the amount of oxidizer flow through the valve. The valve position indicator is mounted on the valve shaft and consists of a rotary-motion, variable resistor and open and close position switches.

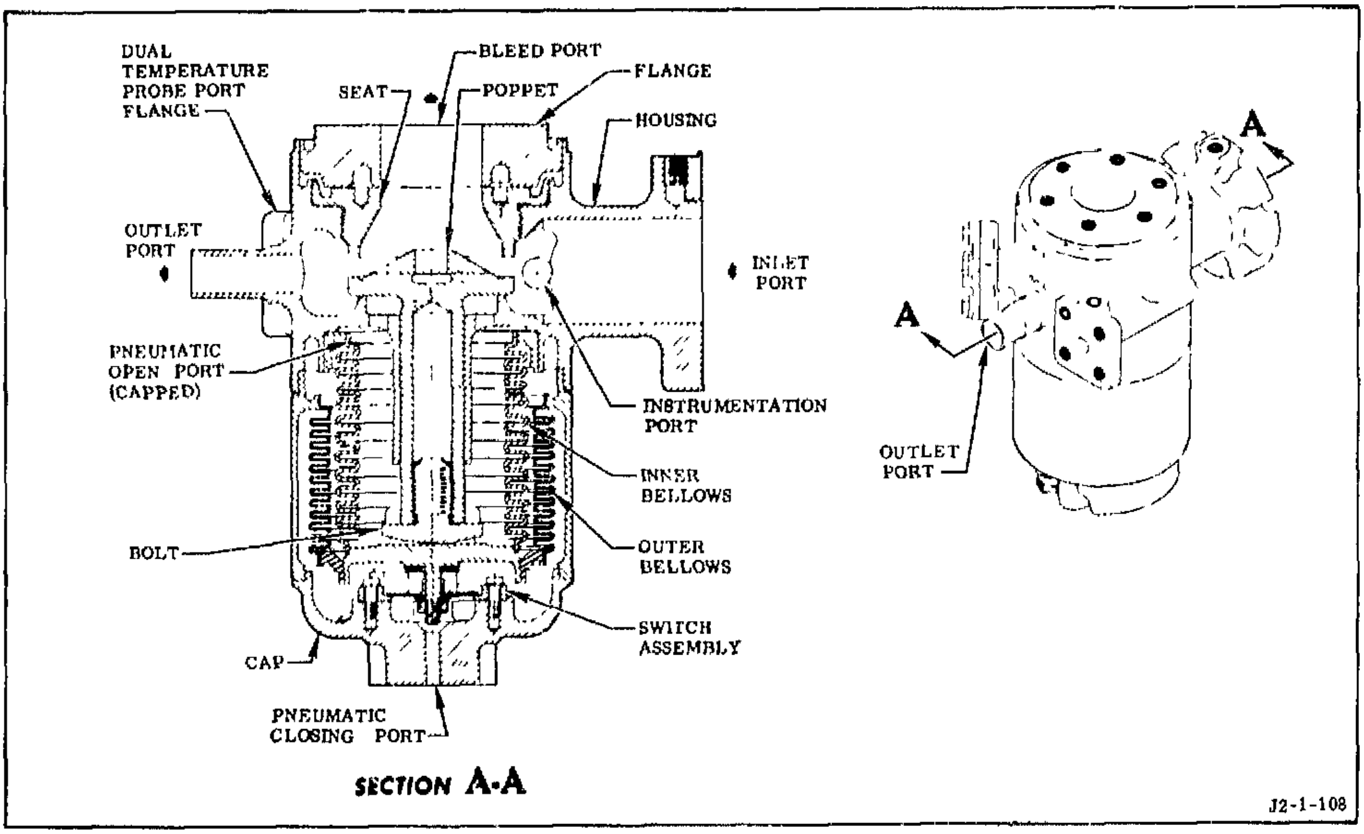

Figure 1-12. Oxidizer Bleed Valve

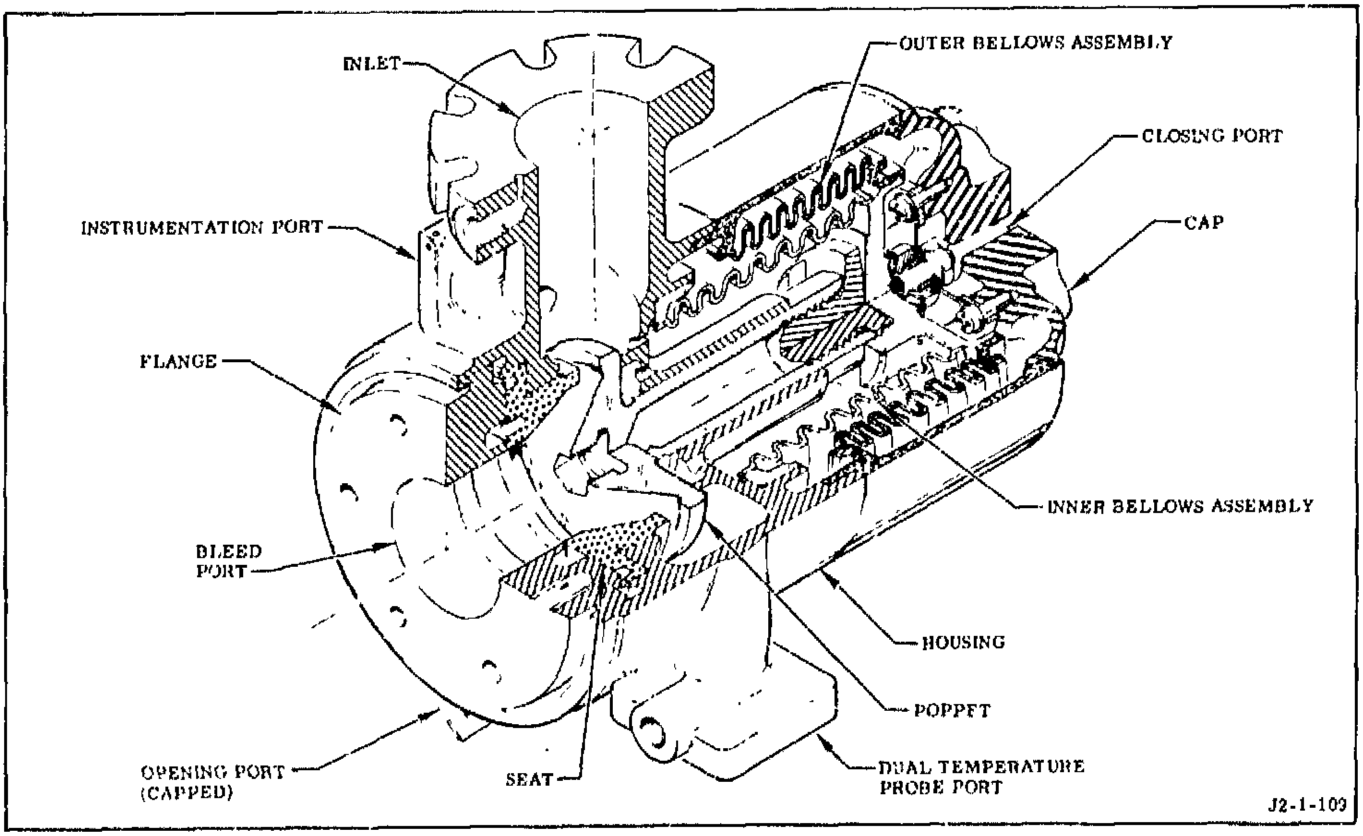

Figure 1-13. Fuel Bleed Valve

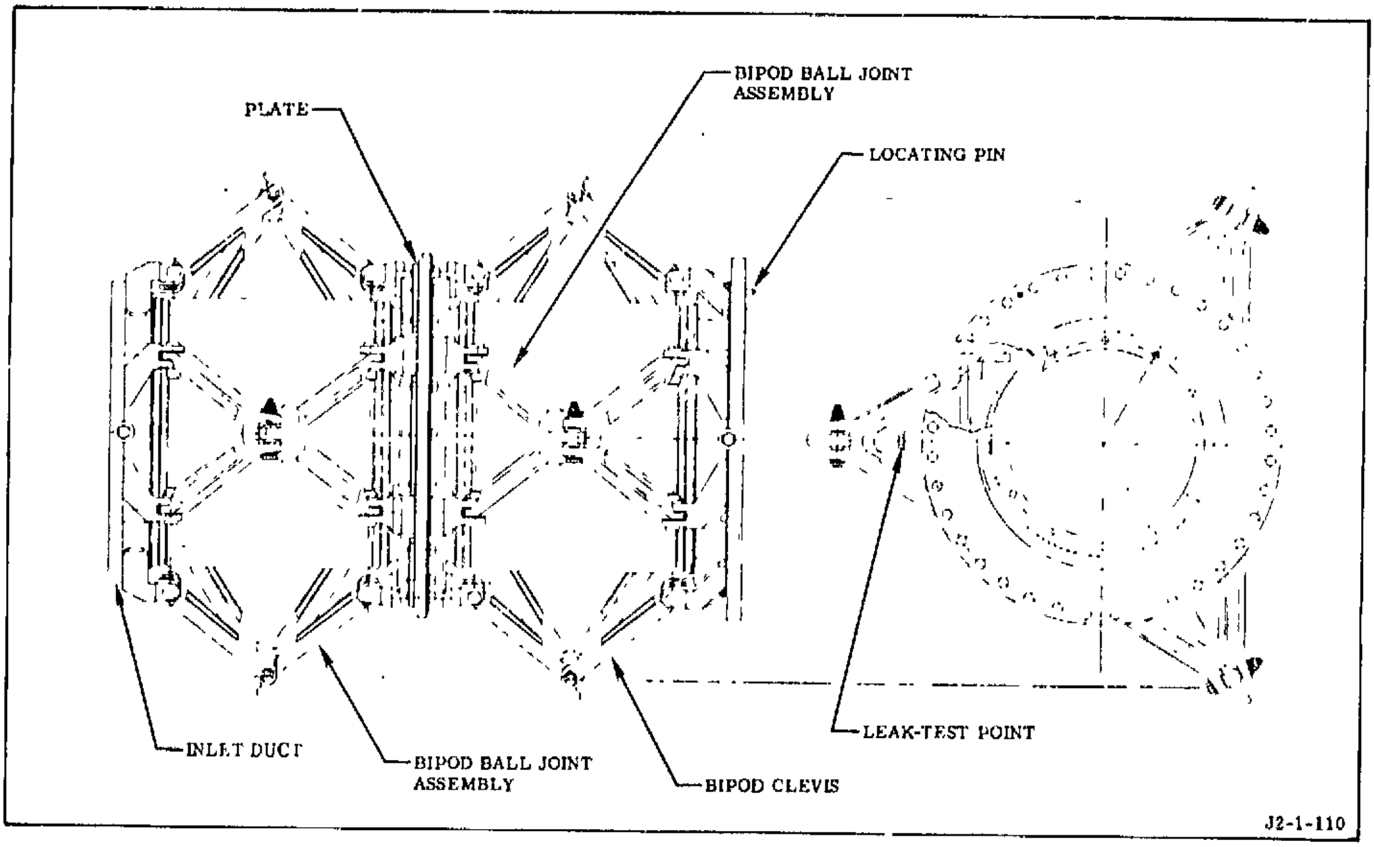

Figure 1-14. Oxidizer Inlet Duct

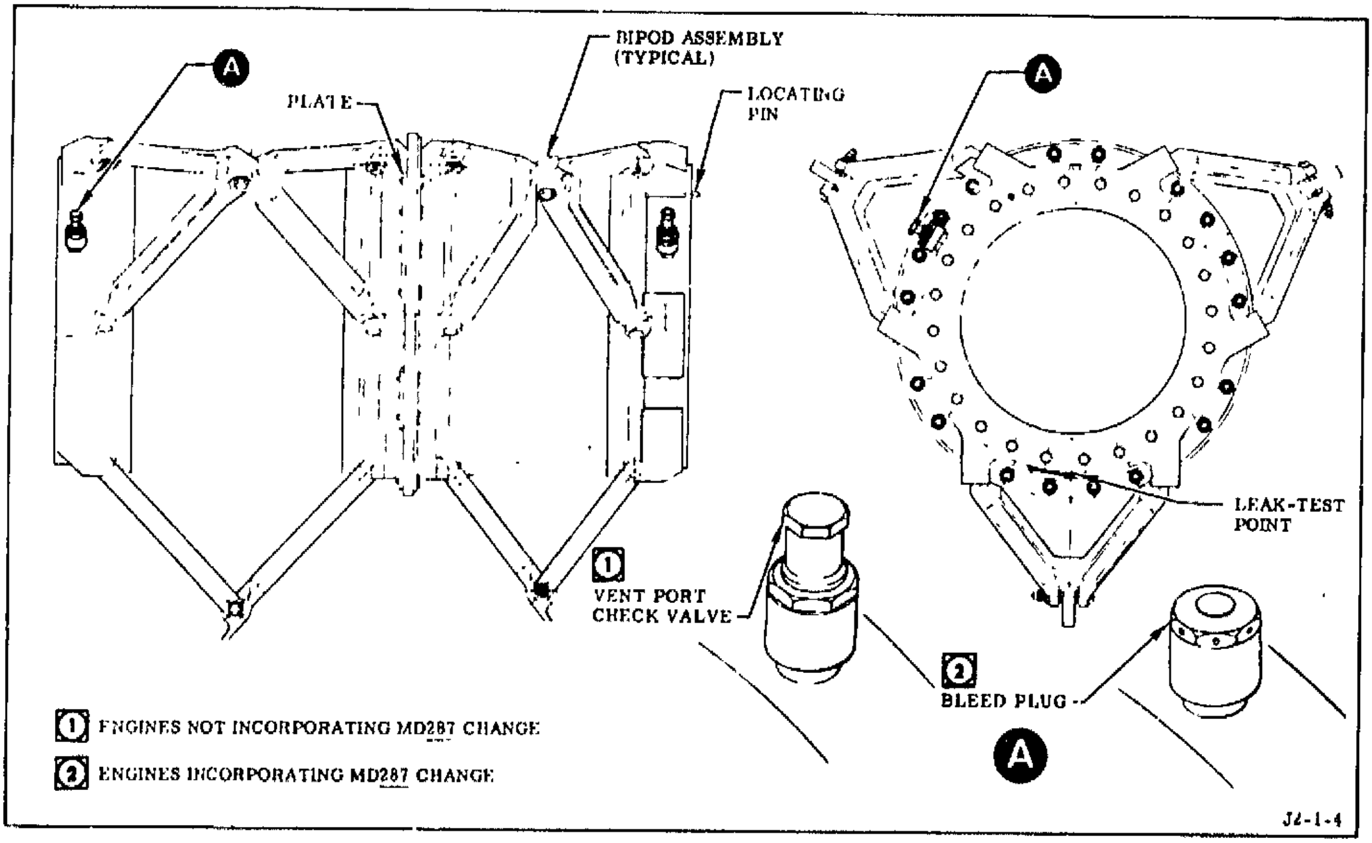

Figure 1-15. Fuel Inlet Duct

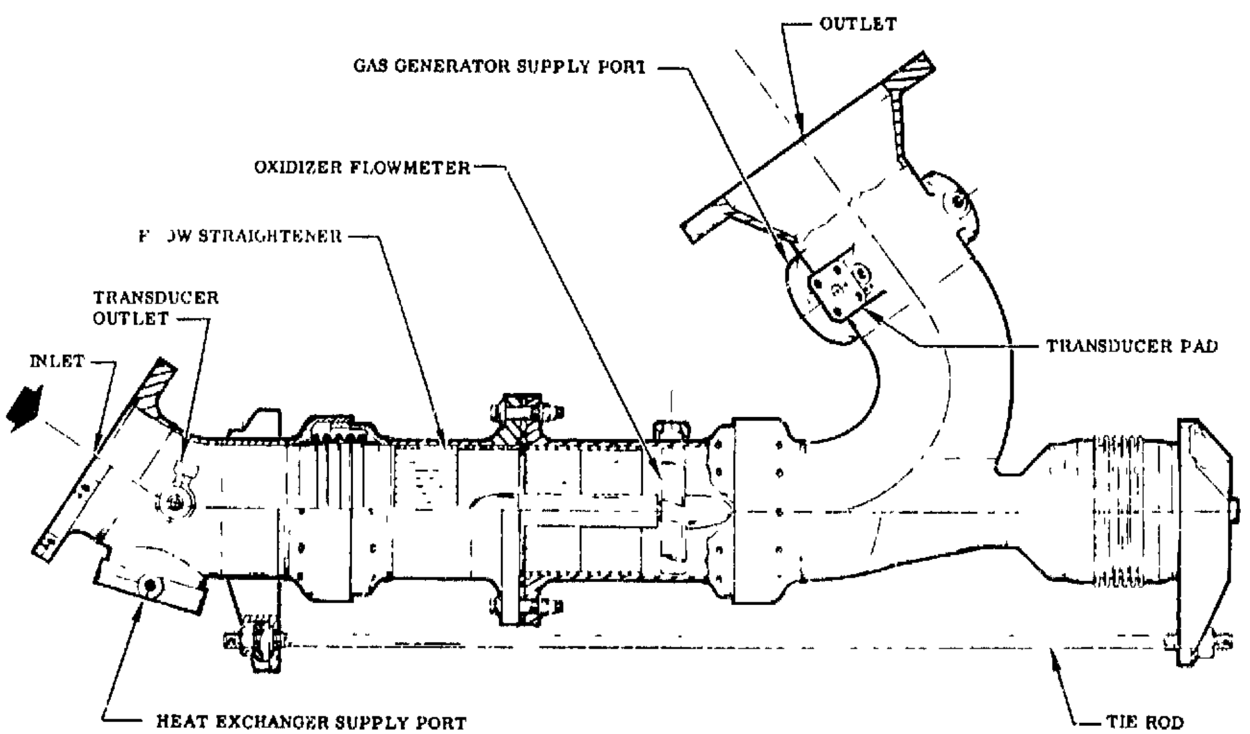

Figure 1-16. Oxidizer High-Pressure Duct

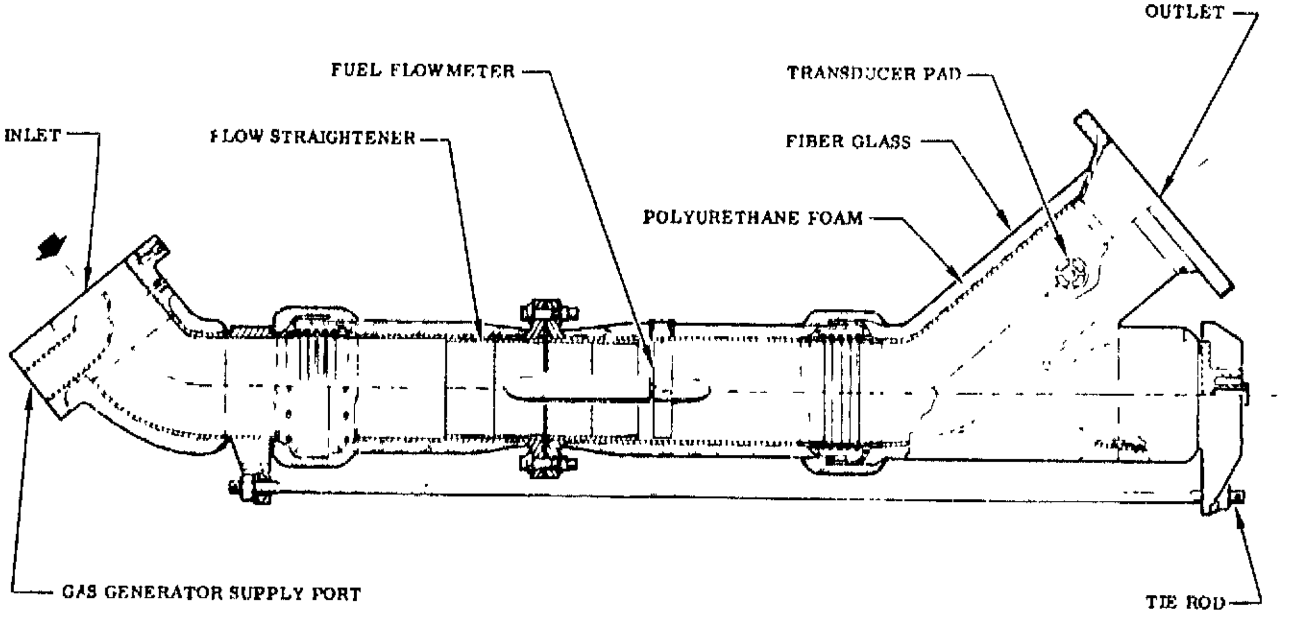

Figure 1-17. Fuel High-Pressure Duct

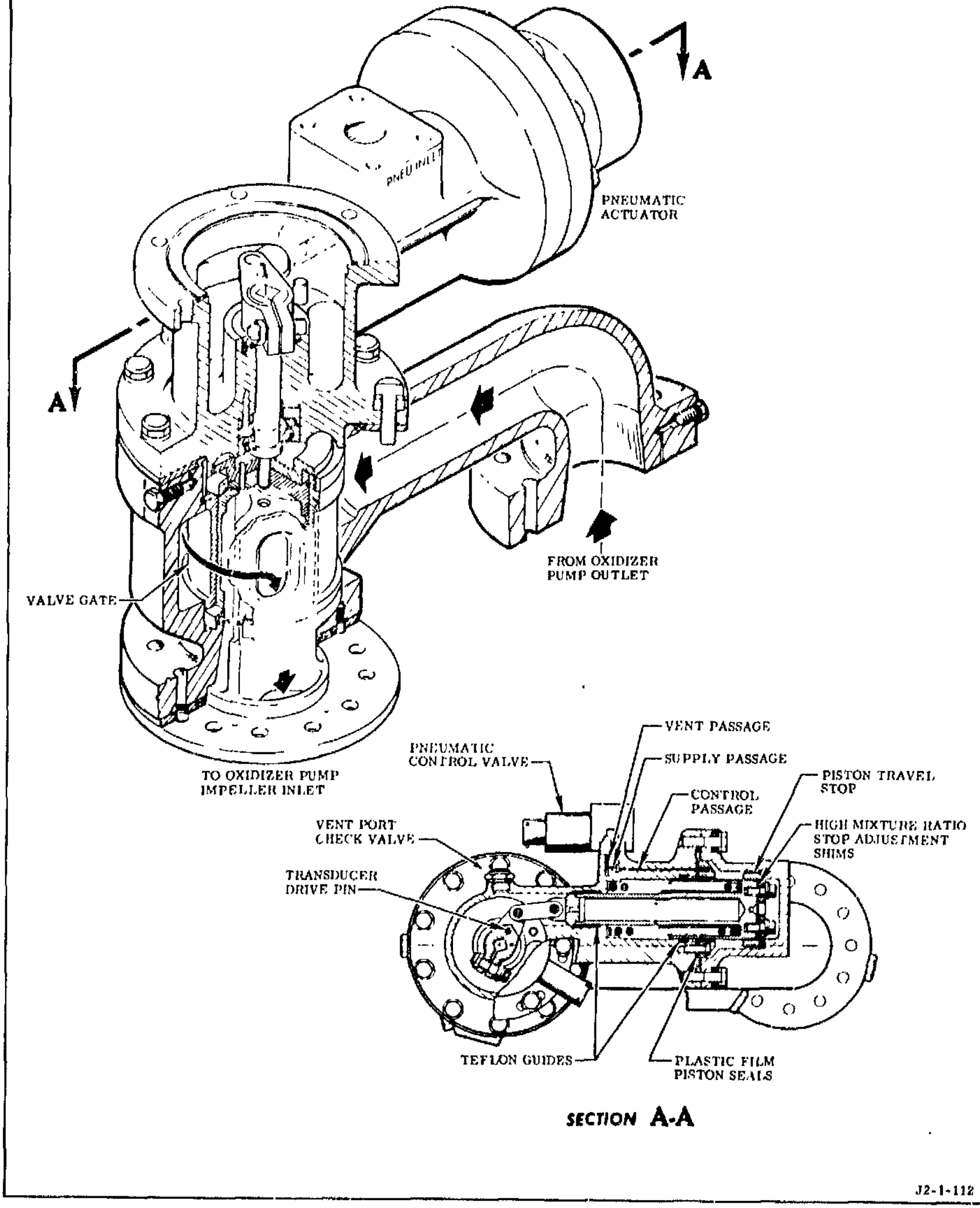

Figure 1-18. Mixture Ratio Control Valve

1-43. The mixture ratio control valve has two distinct stops, to allow engine operation at either 5.5 or 4.8 engine mixture ratio for SII stage engines and SIVB 200-series stage engines or at 5.0 or 4.5 engine mixture ratio for SIVB 500-series stage engines. Pneumatic pressure is supplied to the valve from the engine pneumatic system when the engine helium control valve is energized. At a preselected time during engine operation, a control signal, supplied by the stage, energizes the solenoid control valve. Energizing the solenoid control valve allows pneumatic pressure to enter the valve and apply force to the actuator piston, to overcome the spring tension and move the piston in the direction to rotate the gate to the low engine mixture ratio position (valve open). Opening the valve results in a reduced oxidizer flow to the thrust chamber. If either the pneumatic pressure or the electrical command is lost, the valve will move to the high engine mixture ratio position (valve close). The position indicator arm rotates with the gate shaft, to remotely indicate valve position.

1-44. GAS GENERATING SYSTEM DESCRIPTION.

1-45. The gas generating system provides the power required to operate the oxidizer and fuel turbopumps during engine operation. The system consists of the gas generator that supplies the hot-gases to drive the turbopumps; the turbine exhaust ducts that transfer the exhaust gases from the fuel turbine to the oxidizer turbine and to the thrust chamber exhaust manifold; the heat exchanger that transforms liquid oxygen to gaseous oxygen or conditions stage-supplied helium as an oxidizer tank pressurant; and the oxidizer turbine bypass valve that allows a portion of the turbine exhaust gases to bypass the oxidizer turbopump turbine. The internal power is generated by tapping propellants from the high-pressure ducts and directing them to the gas generator combustor where hot gas is produced to power the turbopumps.

1-46. GAS GENERATOR ASSEMBLY.

1-47. The gas generator assembly (figure 1-19) consists of a control valve and a combustor assembly. The control valve starts or stops the flow of propellants to the oxidizer and fuel injectors. The combustor is welded to the fuel turbopump, and an impingement-type fuel injector and a poppet-type oxidizer injector are assembled into the combustor.

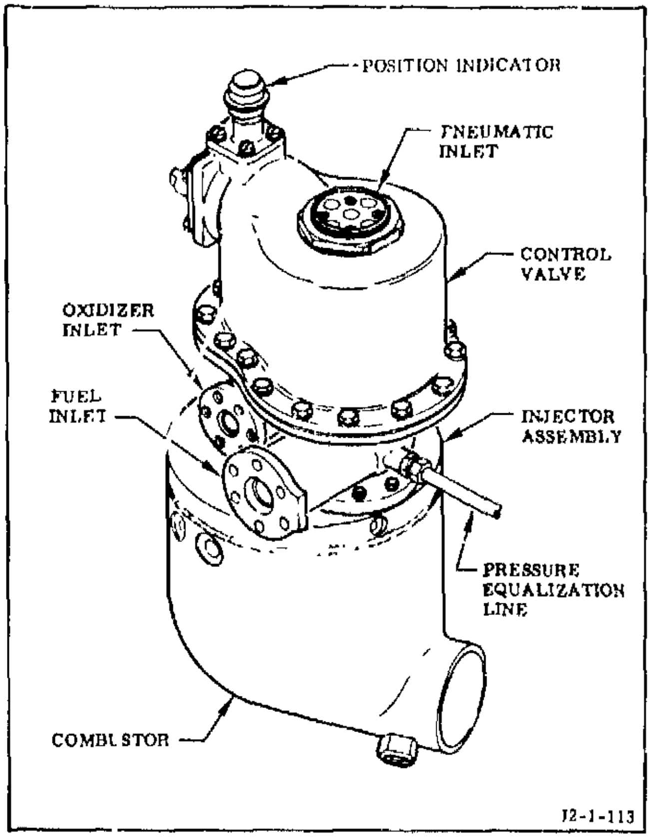

Figure 1-19. Gas Generator Assembly

1-48. GAS GENERATOR CONTROL VALVE. The gas generator control valve (figure 1-20) controls the flow of propellants to the gas generator oxidizer and fuel injectors. The valve is a pneumatically-operated, bellows and spring-loaded-close, dual poppet valve. The valve consists of a fuel body and bellows subassembly, an oxidizer body and bellows subassembly, and a cover that encloses the upper section of both. The fuel body contains a pneumatic actuator assembly which operates the fuel poppet and incorporates a yoke that mechanically actuates the oxidizer poppet following the initial opening movement of the fuel poppet. The fuel and oxidizer poppets have Teflon inserts that are loaded against metal seats by their respective springs and bellows. The pneumatic inlet opening port is incorporated in a retainer that is welded to the bellows of the actuator. The cover contains a flange for installing a cover that provides access to adjust the fuel lead adjustment bolt and valve position indicator. The control valve position indicator consists of two switches that indicate the full open and close positions of the valve, and a linear-motion potentiometer that indicates valve motion. The valve actuator spring cavity is ported through a pressure equalization line to the actuator helium inlet (open) port by the main oxidizer valve sequence valve, to prevent cryopumping when propellants are introduced into the gas generator control valve. The effect of cryopumping is to unbalance the pressure across the actuator piston which results in premature unseating of the fuel poppet.

1-49. During engine start, helium pressure is directed through the pneumatic inlet port to the actuator piston head. Helium pressure is confined in a chamber formed by the inner walls of the retainer and bellows and the outer surface of the piston. The helium pressure moves the actuator piston and opens the fuel poppet. During the fuel poppet opening, the fuel lead adjustment bolt on the yoke contacts the oxidizer bellows assembly and opens the oxidizer poppet. During engine cutoff, as the pneumatic opening pressure decays, the fuel poppet is closed by bellows spring force and propellant pressure acting on the fuel bellows. The oxidizer poppet is closed by the same forces acting on the oxidizer bellows assembly.

1-50. GAS GENERATOR COMBUSTOR. The combustor assembly (figure 1-21) consists of a manifold, a choke ring, a fuel injector, an oxidizer injector, and a combustion chamber that is slightly elongated, with an eight-inch inlet and three-inch outlet. The manifold has a fuel inlet port, an oxidizer inlet port, and a fuel cavity with two slotted outlet ports. The choke ring is welded to the manifold. The fuel injector is threaded and brazed to the manifold and consists of a copper ring with three rows of orifices. The two inner rows have 24 orifices each, and the outer row has 96 orifices. The two inner rows impinge the fuel on the oxidizer, and the outer rows cool the chamber wall. The oxidizer injector consists of a spring-loaded-closed poppet valve and an injector with 24 orifices. The poppet opens at approximately one psi, and oxidizer exits through the orifices and strikes the poppet at a 30-degree angle, is deflected outward, and impinges on the fuel stream. The combustor contains a chamber where the propellants are mixed and burned, and directs the combustion gases to the fuel turbopump turbine. Combustion occurs immediately below the injector faces, and the choke ring confines the high-combustion temperature to this area and directs the hot gas away from the combustor wall and toward the combustor exit.

1-51. OXIDIZER TURBINE BYPASS VALVE.

1-52. The oxidizer turbine bypass valve (figure 1-22) prevents the oxidizer turbopump from overspeeding during engine start and functions as a calibration device during mainstage to establish rpm ratios for the fuel and oxidizer turbopumps. The valve is a pneumatically-actuated, spring-loaded-open valve with a butterfly-type gate and consists of the gate, the actuator, and the position indicator. The gate has a calibrated nozzle (orifice) and is connected to a split shaft that is supported by needle bearings in the valve housing. The actuator piston is loaded to the valve open position by a spring that is retained by the housing cap. A link connects the actuator piston rod to a lever that connects to the gate shaft. The valve position indicator consists of a rotary-motion variable resistor and open and close switches. The position indicator is connected to the gate shaft and provides signals for valve open and close position and valve motion.

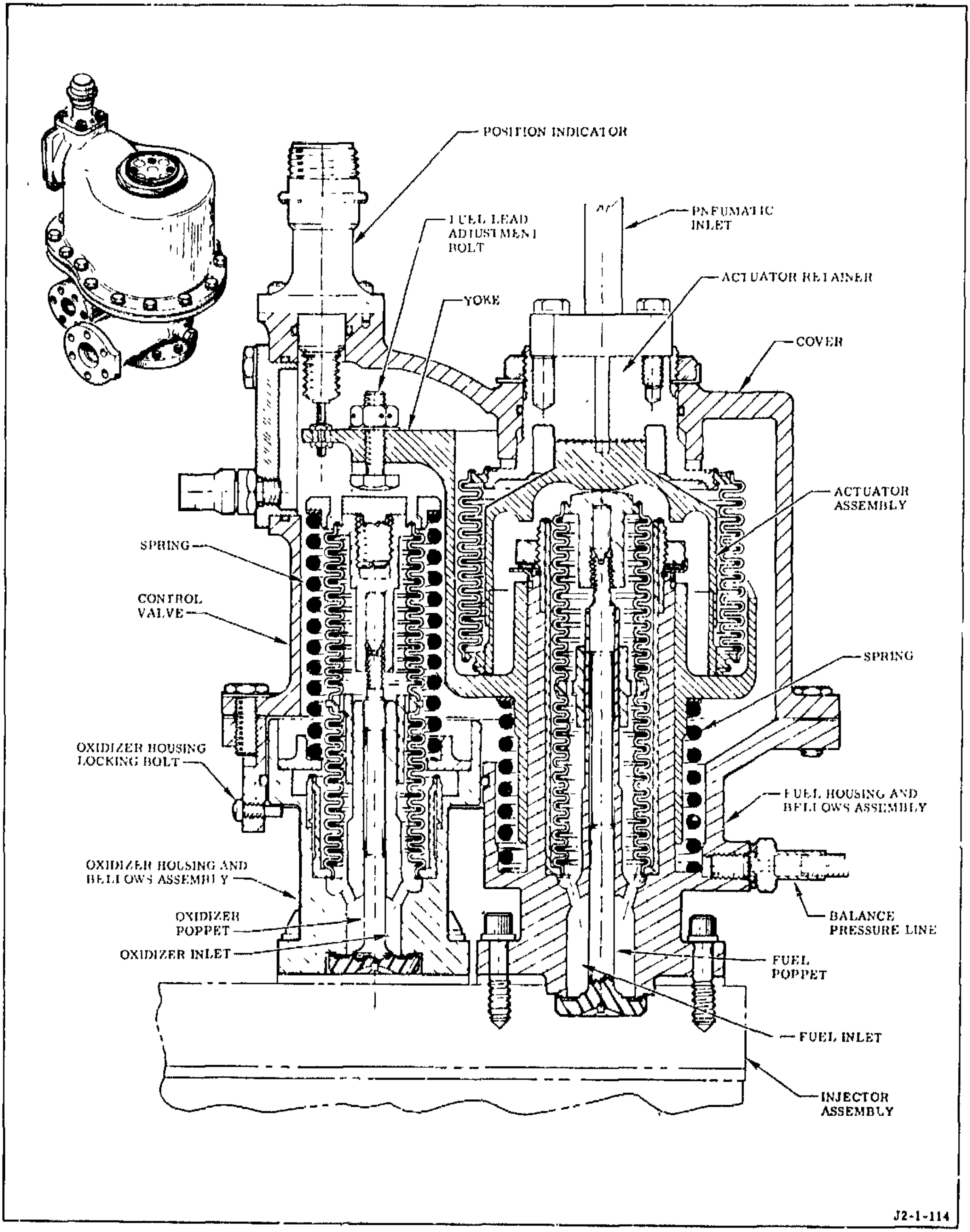

Figure 1-20. Gas Generator Control Valve

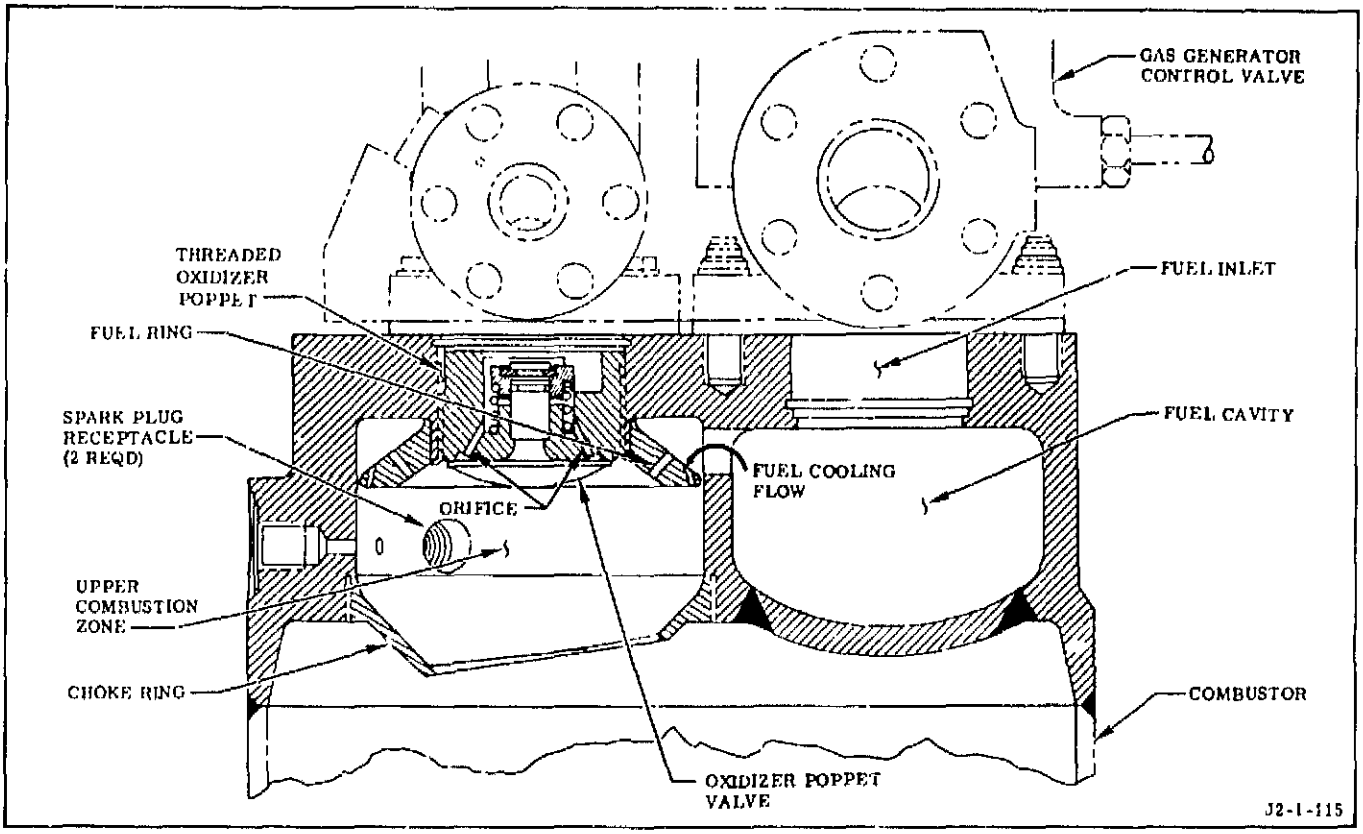

Figure 1-21. Gas Generator Injector

1-53. When the fuel turbopump turbine starts to spin, the exhaust gas in the turbine exhaust duct passes through a duct to the oxidizer turbopump turbine. Some of the gas volume is bypassed through the open oxidizer turbine bypass valve and vented through the thrust chamber. During engine transition into mainstage, helium pressure is directed to the closing control port of the oxidizer turbine bypass valve, closing the valve and directing the turbine exhaust gases through the oxidizer turbopump turbine, except for a volume of gas which passes through the valve gate nozzle. During engine shutdown, closing pressure to the oxidizer turbine bypass valve is vented and spring pressure starts to open the valve. The normally open port of the mainstage control valve supplies pressure to the valve opening control port to help the spring open the valve.

1-54. HEAT EXCHANGER.

1-55. The heat exchanger (figure 1-23) heats and expands stage-supplied helium gas (SIVB stage) or converts liquid oxygen, that is tapped off the oxidizer high-pressure duct, to gaseous oxygen (SII stage) for maintaining stage oxidizer tank pressurization. The heat exchanger is 14 inches in diameter, 16.5 inches long, and connects at the oxidizer turbine outlet and the thrust chamber exhaust manifold. The coil pack consists of four separate coils manifolded to a common inlet and a common outlet. Three supports for the coils maintain loop separation and alinement. The inlet fitting provides for the installation of an orifice plate or a blank plate over each tube. The heat exchanger shell contains a bellows section that compensates for thermal expansion during engine operations. During engine operation, hot gases from the oxidizer turbine are directed through the heat exchanger where a portion of the heat is transferred to the coils. In the resulting heat transfer, liquid oxygen in the coils is converted to gaseous oxygen, or helium in the coils is expanded for stage oxidizer tank pressurization.

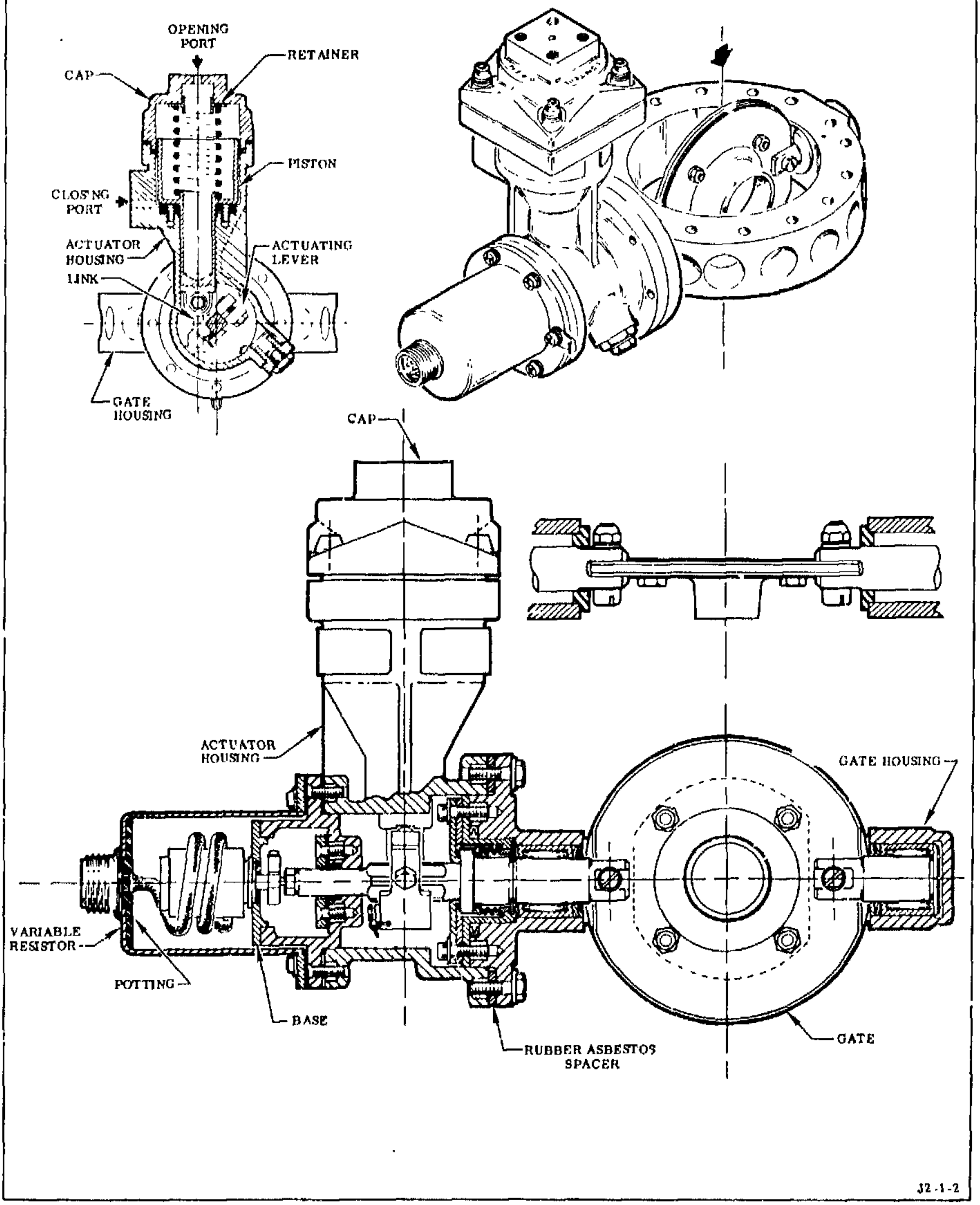

Figure 1-22. Oxidizer Turbine Bypass Valve

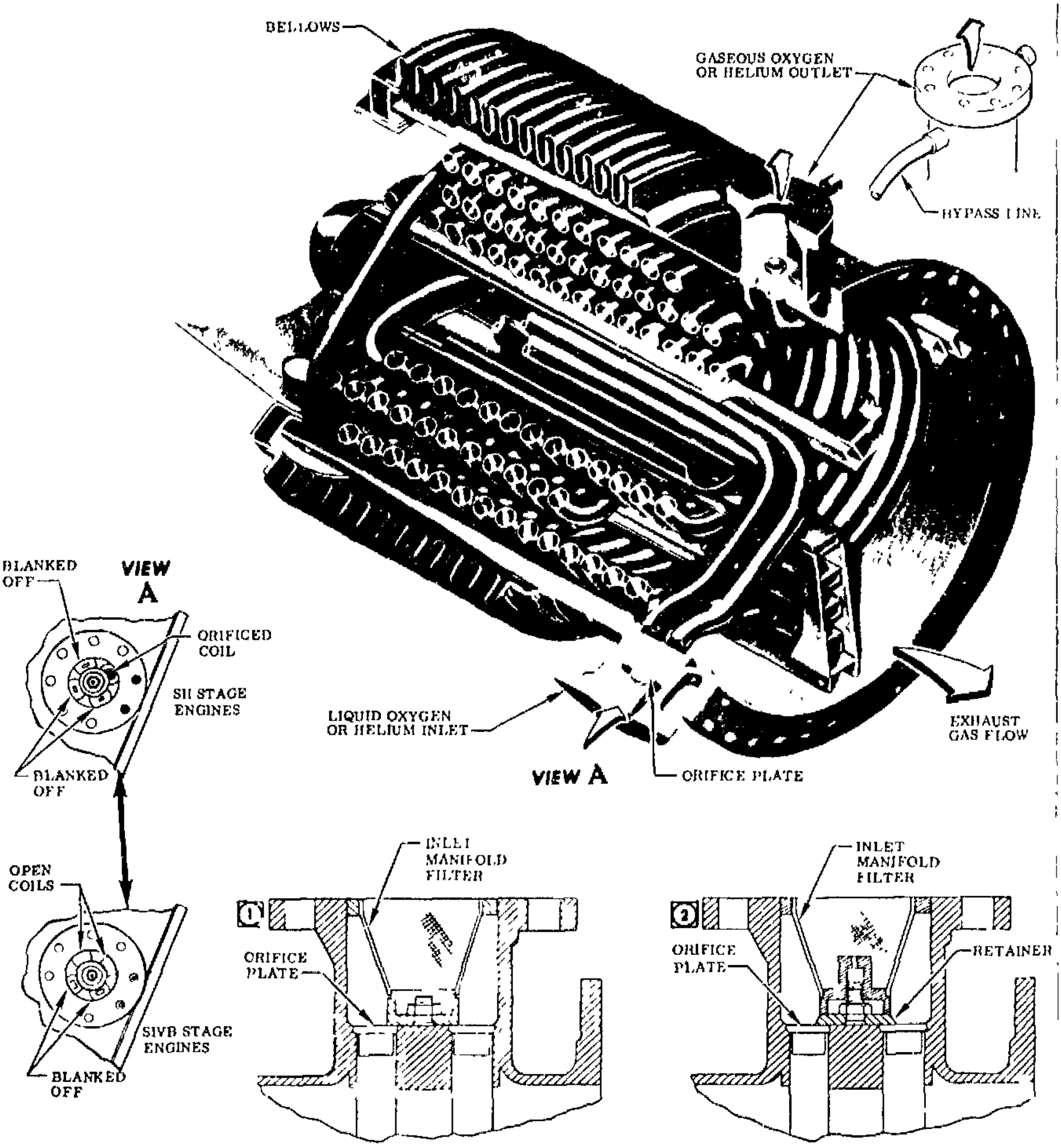

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Figure 1-23. Heat Exchanger

1-56. ANTIFLOOD CHECK VALVE.

1-57. The antiflood check valve (figure 1-24) is mounted on the heat exchanger oxidizer inlet line and prevents filling of the heat exchanger before engine start. The valve is within a basic envelope of 7.5 inches by 7.5 inches by 14 inches. When helium is used as the stage oxidizer tank pressurant, the antiflood check valve and heat exchanger oxidizer supply line are removed from the engine. The antiflood check valve is a piston-type check valve incorporating a bypass. The bypass senses differential pressure between the heat exchanger inlet and outlet ports, and effectively functions as a regulator for the liquid oxygen entering the heat exchanger. The valve consists of a body, a piston, a poppet, a spring, a plug, and a cap. The piston has a hole through the center, with the poppet in one end of the hole and the plug in the other end. The piston and poppet are spring-loaded to the close position. The cap retains the spring and incorporates the gaseous oxygen pressure sensing port (bypass). During engine operation, liquid oxygen under pump pressure unseats the piston and flows through the valve and into the heat exchanger coils. Gaseous oxygen pressure at the heat exchanger outlet is sensed at the valve bypass port, where it applies pressure to the spring side of the piston. The spring maintains a differential pressure of approximately 25 psi between heat exchanger inlet and outlet pressures, with the outlet (gaseous oxygen) pressure being the lower. If the differential pressure increases, the valve moves further open to admit more liquid oxygen into the heat exchanger. If the differential pressure decreases, the valve moves toward the closed position to decrease the amount of liquid oxygen entering the heat exchanger.

1-58. EXHAUST DUCTING.

1-59. The exhaust ducting routes gas generator exhaust gases to the thrust chamber exhaust manifold. The exhaust ducting consists of the fuel turbine exhaust duct (crossover duct), oxidizer turbine bypass duct, and the exhaust manifold. The fuel turbine exhaust duct and the bypass duct have bellows sections to compensate for thermal expansion during engine operation. The exhaust manifold is a tapered manifold that encircles the thrust chamber bell. The manifold has two inlets; the larger inlet is the main exhaust inlet from the heat exchanger and the other inlet is for the oxidizer turbine bypass gas. The manifold outlet is through openings between the long (up) tubes (cat-eyes) along the inside diameter of the thrust chamber. The fuel turbine exhaust duct routes the hot gas from the fuel turbine to the oxidizer turbine inlet. From there the hot gas is routed through the heat exchanger and into the exhaust manifold, which dumps the gas into the thrust chamber bell. Hot gas also leaves the fuel turbine through the oxidizer turbine bypass duct, which directs a portion of the gas to bypass the oxidizer turbopump turbine, and flows directly into the exhaust manifold.

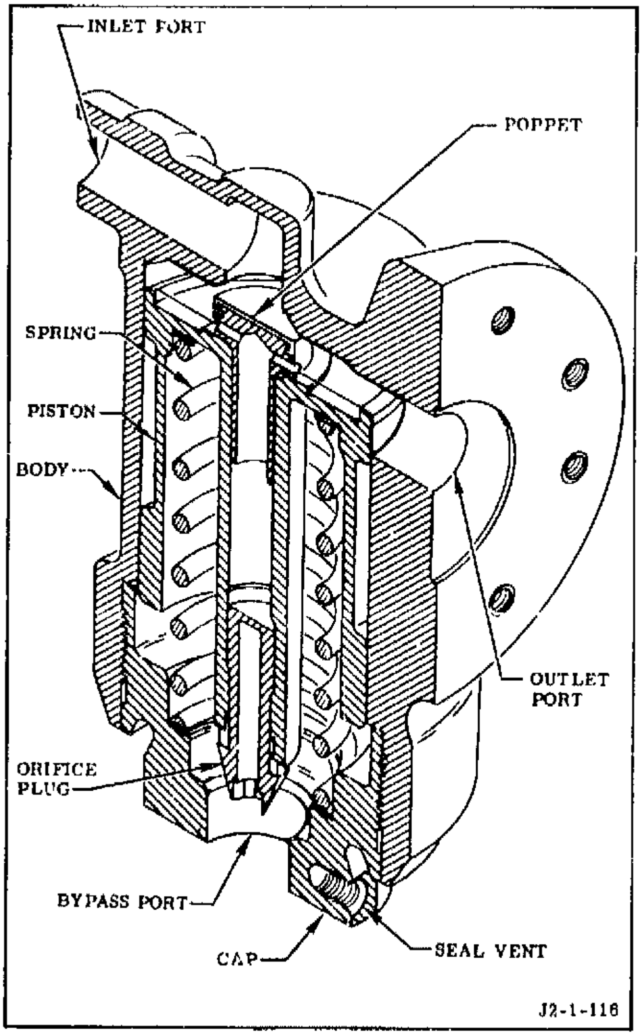

Figure 1-24. Antiflood Check Valve

1-60. START SYSTEM DESCRIPTION.

1-61. The start system stores gaseous hydrogen under pressure and releases and directs this pressure to initially spin the turbopumps at engine start. The system comprises a hydrogen start tank that contains gas for starting the engine; a start tank discharge valve that contains the gas in the start tank until engine start; a start tank support-and-fill valve that permits the flow of supply gases to the start tank; a vent-and-relief valve that relieves excessive pressure or vents the start tank; and an emergency vent valve that provides redundant venting of start tank pressure in an emergency during ground operations.

1-62. START TANK.

1-63. The start tank (figure 1-25) consists of a 4.2-cubic-foot capacity, 25.5-inch diameter sphere for storing hydrogen. A 1,000-cubic-inch capacity sphere for storing helium is located within the tank. The start tank is insulated to prevent excessive internal pressure buildup caused by external temperatures. The start tank is initially filled from a ground source. On restart mission engines, the tank is refilled, during engine operation, with gaseous hydrogen bled from the thrust chamber fuel injection manifold and with liquid hydrogen bled from the augmented spark igniter fuel line.

1-64. START TANK SUPPORT-AND-FILL VALVE.

1-65. The start tank support-and-fill valve (figure 1-26) consists of two poppet-type check valves, two filters, an accessory flange, and a dual-purpose port in the housing. One check valve allows hydrogen flow into the tank from a ground source, and the other check valve permits flow into the tank from a tapoff on the thrust chamber fuel injection manifold. The filters maintain cleanness of the hydrogen flowing into the tank from the fill sources. The start tank emergency vent valve is mounted on the valve accessory flange. The dual-purpose port is used as an instrumentation port to monitor tank pressure and to receive hydrogen from the augmented spark igniter fuel line for tank topping. During operation, gaseous hydrogen pressure unseats the check valve poppet to allow the tank to pressurize. After the tank is pressurized, spring pressure reseats the poppet and prevents loss of gaseous hydrogen when the engine is not operating.

1-66. START TANK LIQUID REFILL CHECK VALVE.

1-67. The start tank liquid refill check valve (figure 1-27) prevents the flow of pressurant into the engine system during ground fill and when the start tank is pressurized. The check valve is a poppet-type valve, spring-loaded to the closed position. Liquid hydrogen enters the check valve through a screen, unseats the poppet, and flows through an orifice to the valve outlet. This check valve is installed only on restart mission engines.

1-68. START TANK EMERGENCY VENT VALVE.

1-69. The start tank emergency vent valve (figure 1-28) provides a redundant means of venting pressurized gas from the start tank. The valve is actuated, in an emergency, from a ground source. The emergency vent valve is a solenoid-operated, two-way, spring-loaded to the closed position, poppet-type valve mounted on the start tank support-and-fill valve. The valve spring holds the poppet on the seat, against start tank pressure, when the solenoid is deenergized. When the solenoid is energized, the armature moves to overcome the spring pressure, allowing the flexure to unseat the poppet and vent start tank pressure through the valve outlet. The outlet is connected to a line that is teed to the fuel turbopump primary seal drain line.

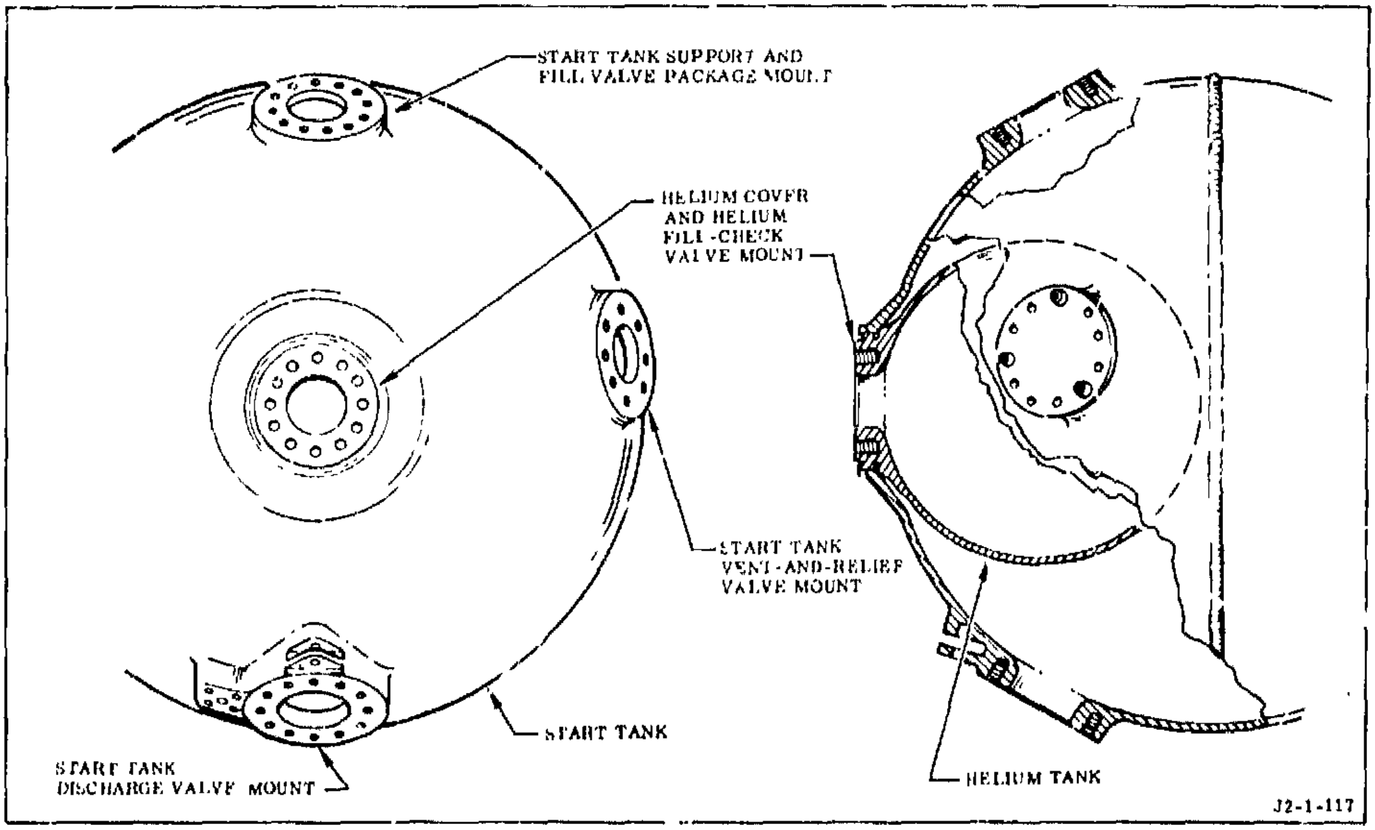

Figure 1-25. Start Tank

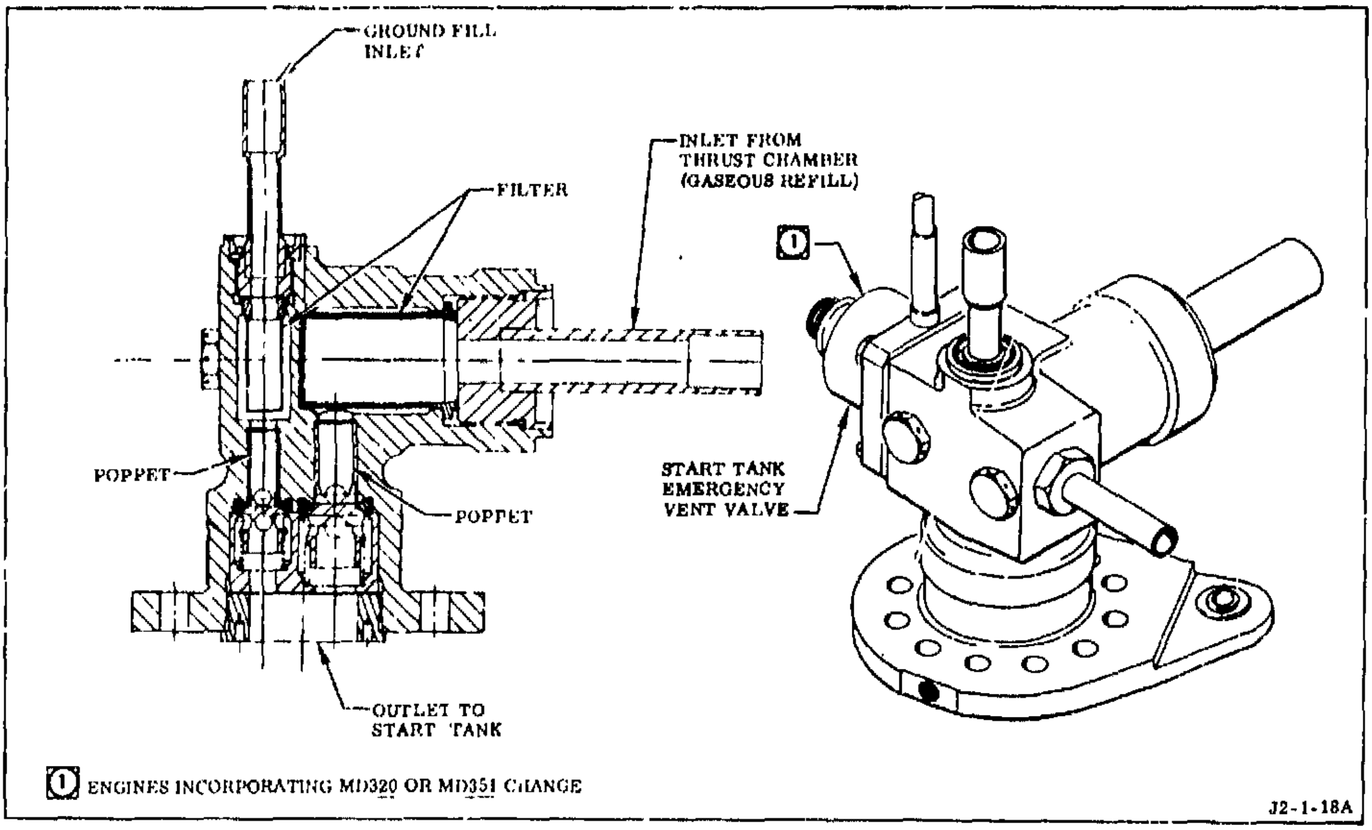

Figure 1-26. Start Tank Support-and-Fill Valve

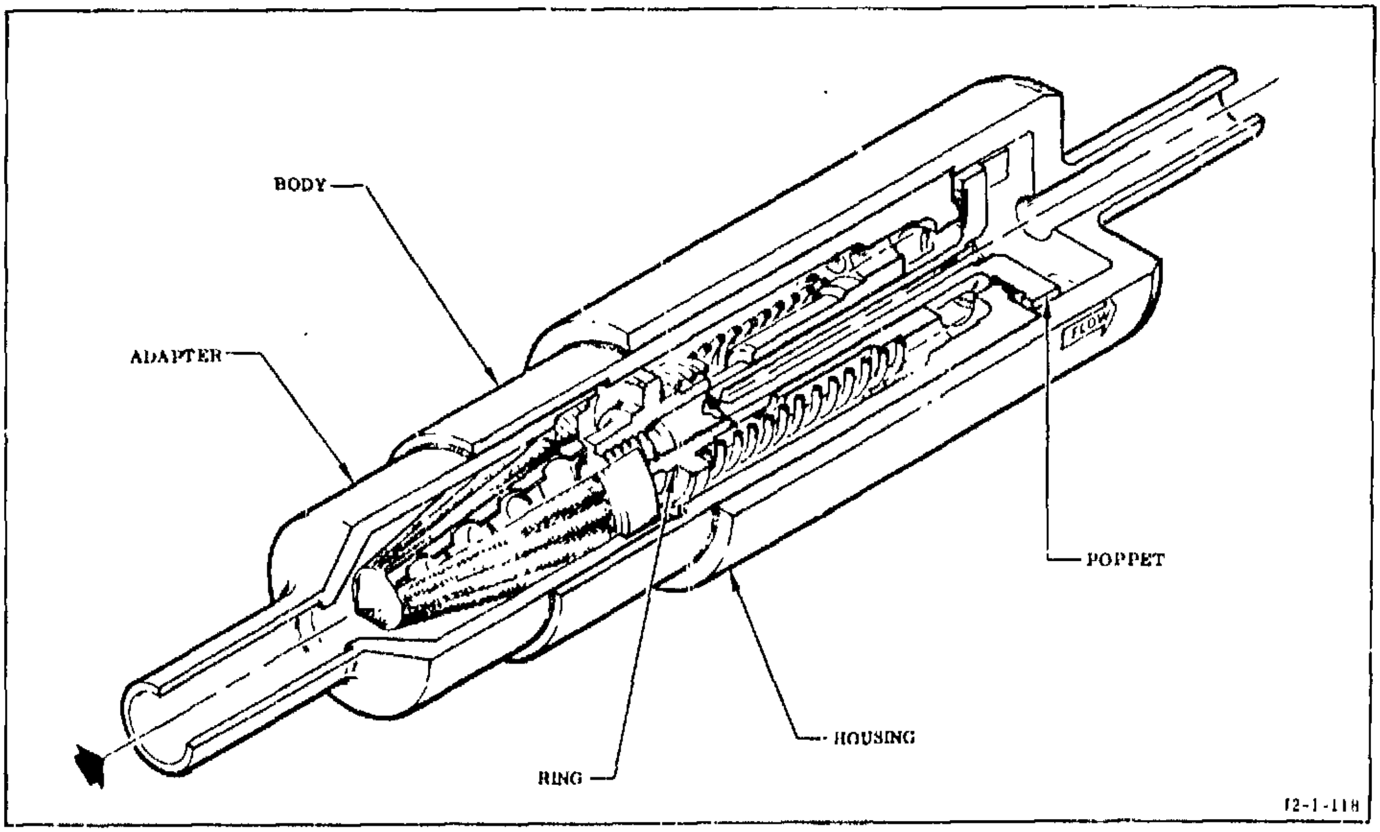

Figure 1-27. Start Tank Liquid Refill Check Valve

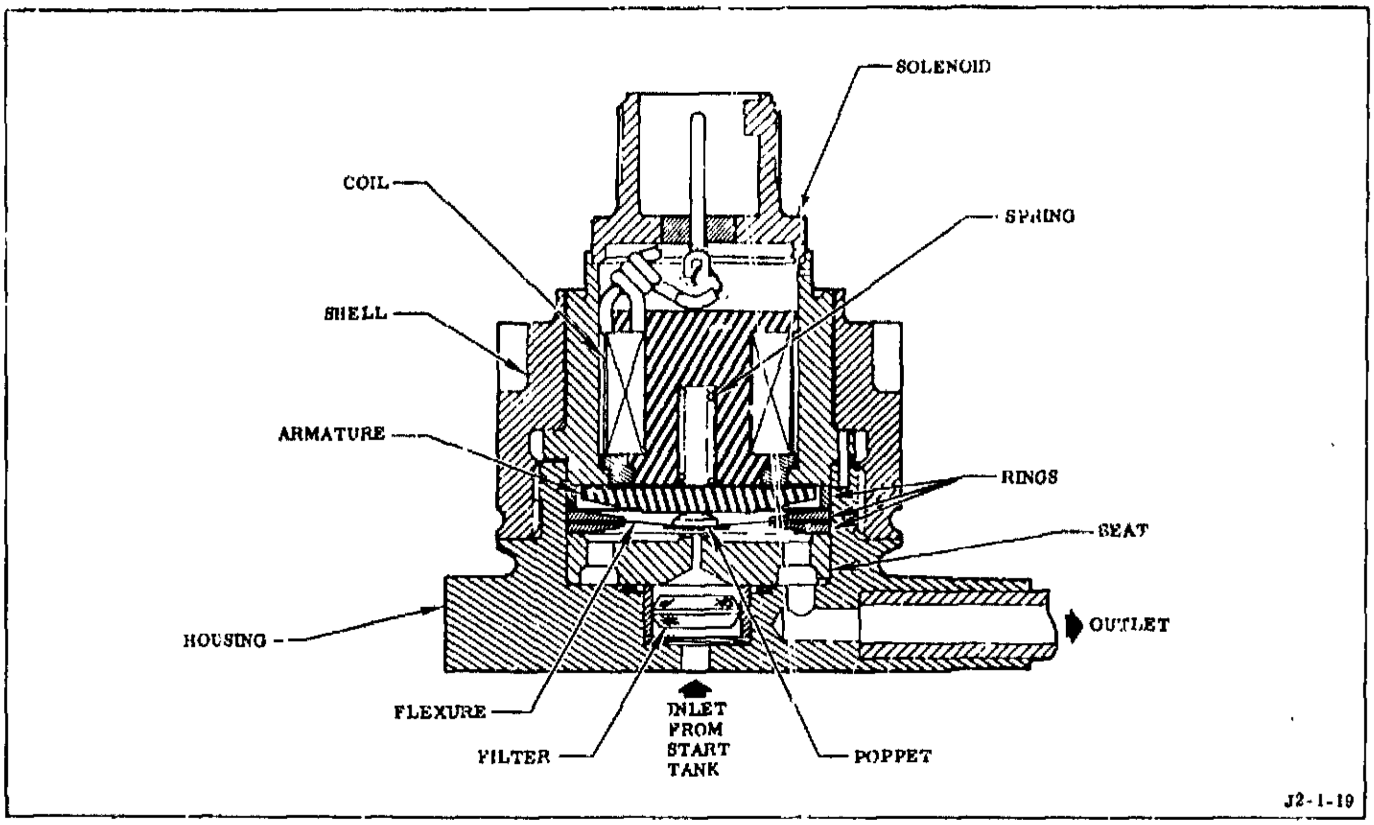

Figure 1-28. Start Tank Emergency Vent Valve

1-70. START TANK DISCHARGE VALVE.

1-71. The start tank discharge valve (figure 1-29) starts or stops the flow of gas from the start tank to the turbines. The valve is a pneumatically actuated, spring-loaded to the closed position, poppet-type valve, mounted on one of the start tank flanges. The start tank discharge valve outlet incorporates a spring-loaded closed, swing gate check valve to prevent hot gas, from the gas generator, from entering the valve during engine operation. A valve position indicator, consisting of two switches and a linear-motion potentiometer, remotely indicates valve position. During engine start, when the start tank discharge valve control valve is energized, pneumatic pressure is directed to the opening port of the start tank discharge valve, and the closing port is vented. Pressure builds up on the opening control side of the piston and moves the piston and shaft, unseating the bellows seal and actuating the position switch. Gas from the start tank passes under the bellows seal and opens the check valve swing gate against spring tension. During engine transition into mainstage, the control valve is deenergized, venting the start tank discharge valve opening port and directing pneumatic pressure to the valve closing port. Pneumatic pressure, aided by spring tension, closes the valve. The swing gate check valve is then closed by spring tension.

1-72. START TANK VENT-AND-RELIEF VALVE.

1-73. The start tank vent-and-relief valve (figure 1-30) prevents overpressurization of the start tank and is used as a control for tank venting. The valve is a spring-loaded closed, pneumatically actuated open, poppet-type, dual-purpose valve. The vent portion of the valve is stage controlled and starts or stops the flow of gas out of the start tank. The relief portion of the valve prevents excessive pressure buildup in the start tank. To vent the valve, pneumatic pressure is applied to the control port from a stage source. Control pressure moves the actuator diaphragm and push rod, which unseats the poppet. Gas from the start tank passes through the filter and into the spring cavity of the bolt, around the unseated poppet, past the push rod into the vent-and-relief manifold, and overboard through the outlet port. When control pressure is removed, the override spring repositions the push rod, to permit the poppet to reseat and stop the venting operation. The relief portion of the valve automatically operates, when excessive inlet pressure acts against the relief diaphragm to compress the relief springs and move the bolt down, which unseats the poppet and relieves excessive pressure through the same path it took during venting operation.

1-74. IGNITION SYSTEM DESCRIPTION.

1-75. The ignition system initiates combustion in the thrust chamber and gas generator by providing the necessary temperature and pressure to ignite the propellants. The system consists of the augmented spark igniter that receives the initial flow of oxidizer and fuel for ignition in the thrust chamber; the augmented spark igniter valve that permits or stops the flow of oxidizer to the augmented spark igniter; the spark igniter and cable assembly that transmits the electrical energy from the spark exciters located in the electrical control assembly to the spark igniters; and the ignition detector probe that senses combustion temperature in the augmented spark igniter chamber.

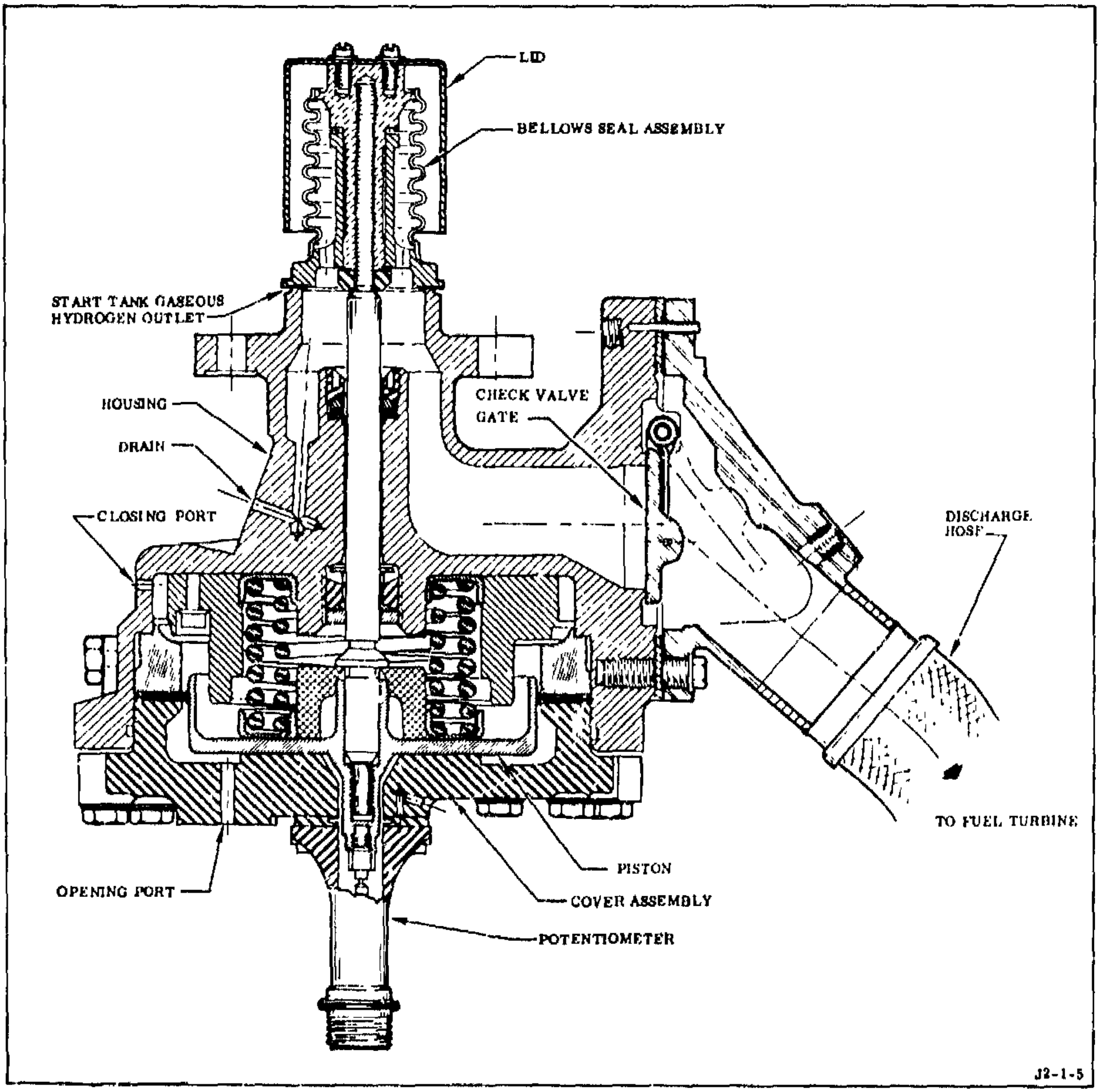

Figure 1-29. Start Tank Discharge Valve

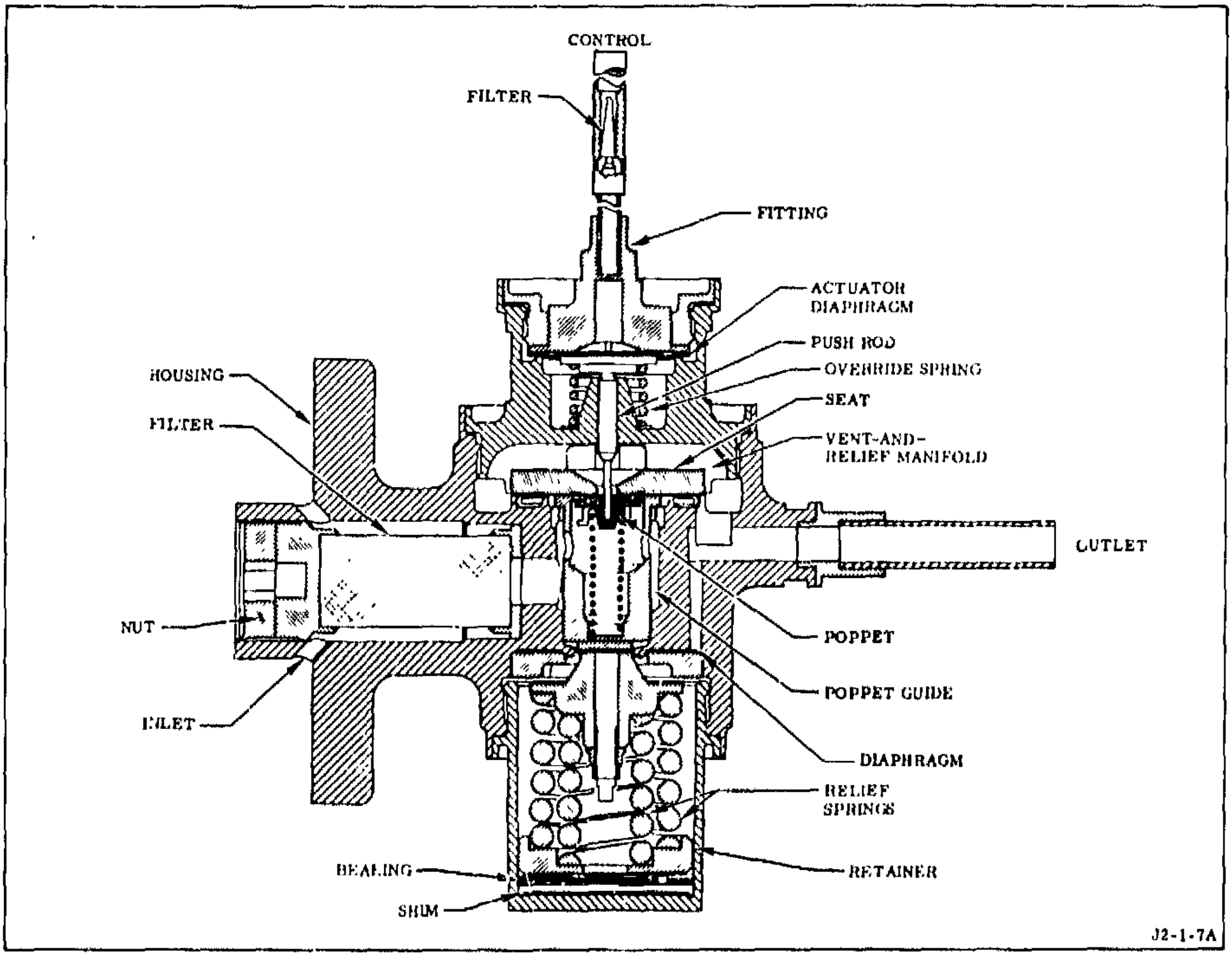

Figure 1-30. Start Tank Vent-and-Relief Valve

1-76. AUGMENTED SPARK IGNITER.

1-77. The augmented spark igniter (figure 1-31) is a chamber mounted in the center of the thrust chamber injector. The igniter has passages for fuel and oxidizer and has provisions for mounting two spark igniters (spark plugs) and the ignition detector probe. The augmented spark igniter receives the initial flow of oxidizer and fuel, that is ignited by the two spark plugs mounted in the side of the igniter chamber. When engine start is initiated, the spark exciters energize the spark plugs in the augmented spark igniter. Simultaneously, the control system starts the flow of oxidizer and fuel to the spark igniter; as the oxidizer and fuel enter the chamber, they are mixed and ignited. To provide for a shorter ignition delay, an oxidizer lead is used.

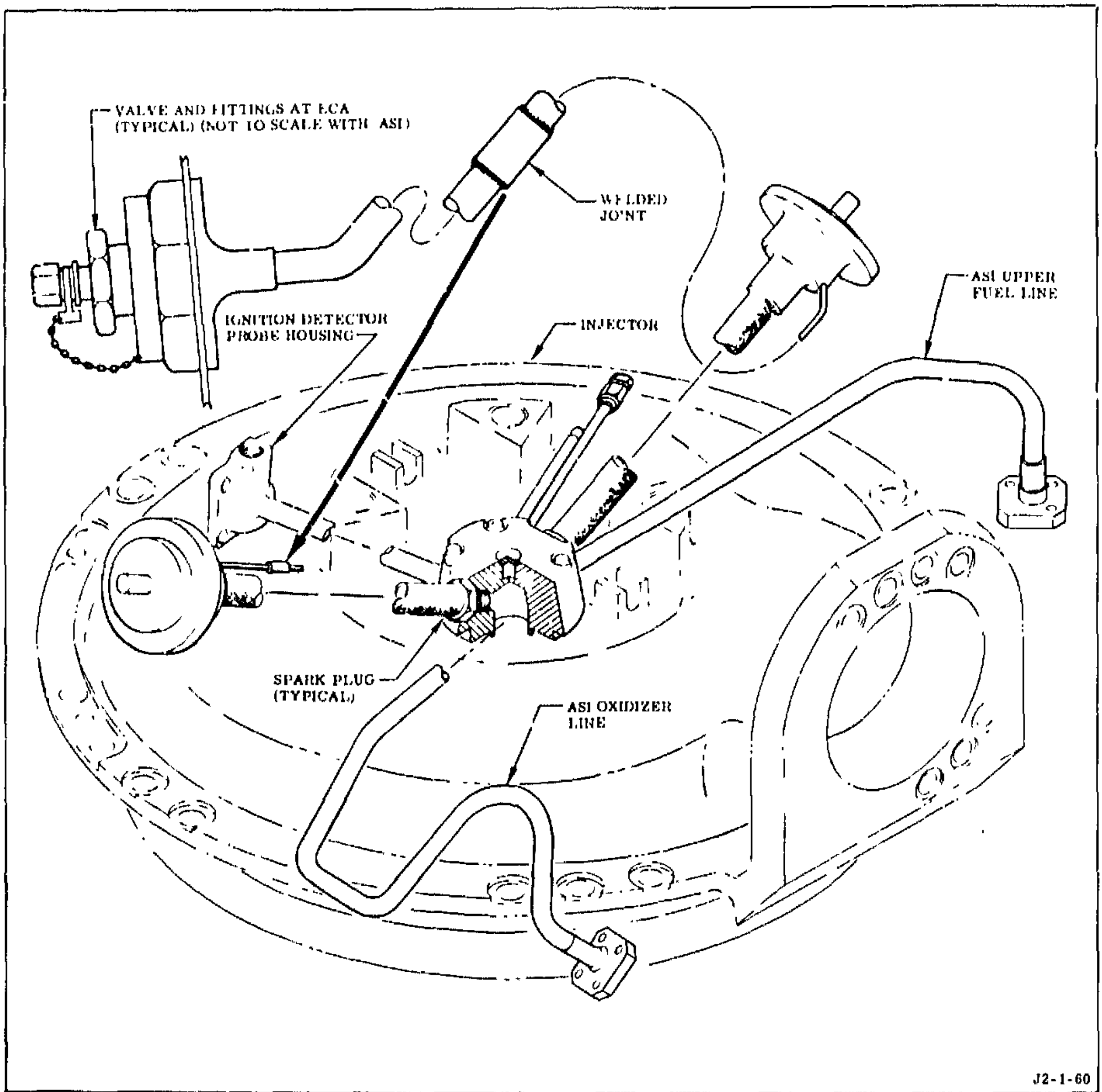

Figure 1-31. Augmented Spark Igniter

1-78. AUGMENTED SPARK IGNITER VALVE.

1-79. The augmented spark igniter valve (figure 1-32) starts or stops the flow of oxidizer to the augmented spark igniter. The valve is a normally closed, pneumatically operated, poppet valve mounted on the main oxidizer valve. The valve consists of a bellows actuator; a bellows cover that has the pneumatic opening port; and a housing that contains the oxidizer passage, the pneumatic closing port, and the position switch electrical connector. The bellows assembly isolates the pneumatic pressure from the oxidizer and is welded into the housing. The oxidizer inlet poppet is attached to the isolation bellows assembly. Oxidizer at the stage tank pressure is present at the valve poppet before engine start. During engine start, pneumatic pressure is routed to the valve opening port. Pneumatic pressure compresses the bellows and opens the poppet, allowing oxidizer to flow through the valve to the augmented spark igniter. The position switch electrical contacts provide a valve open signal. During engine shutdown, opening pressure to the valve is vented and pneumatic pressure is routed to the valve closing port. Pneumatic pressure, assisted by bellows spring force, closes the valve.

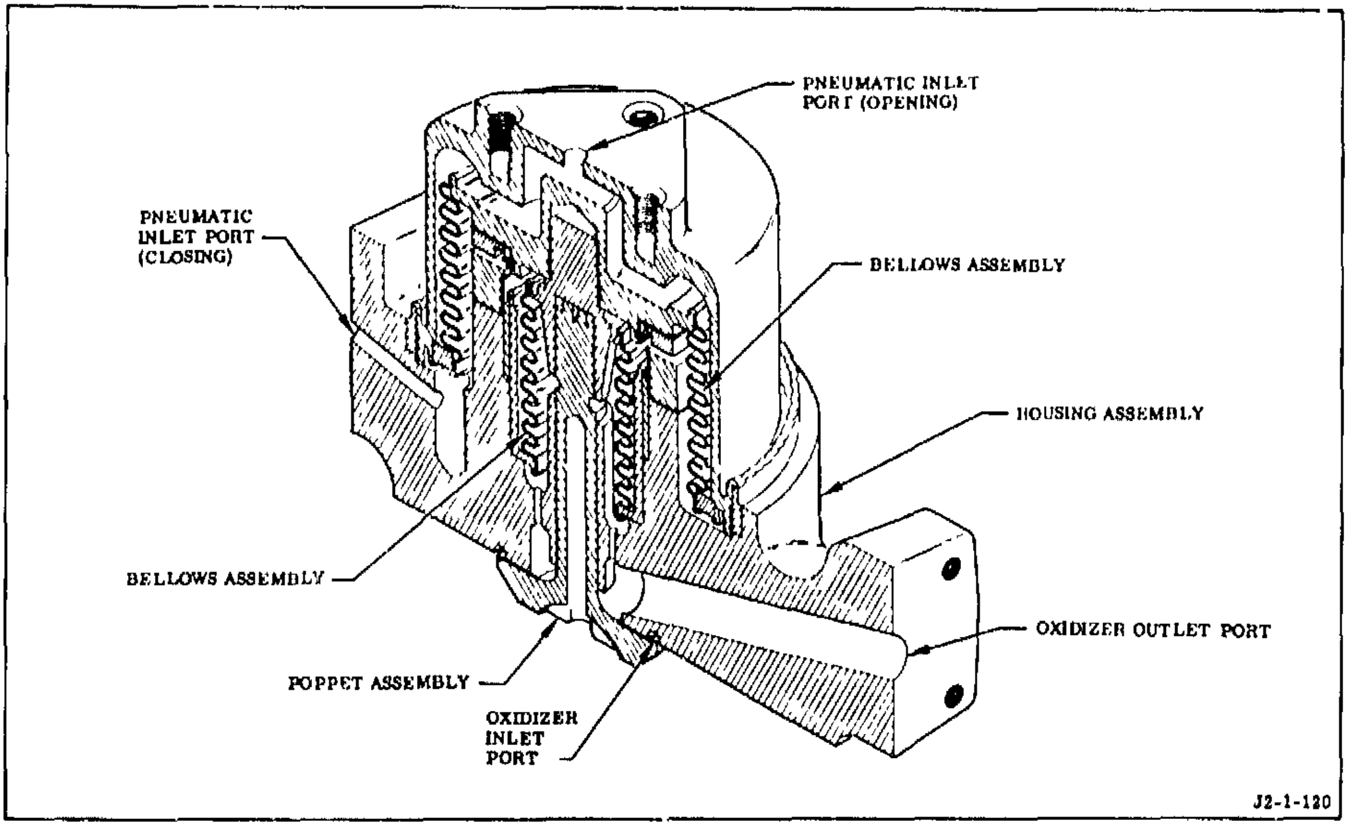

Figure 1-32. Augmented Spark Igniter Valve

1-80. SPARK IGNITER CABLE ASSEMBLY.

1-81. The spark igniter cable assembly (figure 1-33) transmits the electrical energy from the spark exciters, located in the electrical control assembly, to the igniters in the augmented spark igniter and the gas generator. To provide maximum reliability, a redundant system, consisting of four separate assemblies, is used. Two assemblies are connected to the gas generator and two to the augmented spark igniter. Each assembly consists of a cable, igniter (spark plug), and the bell housing. The cable consists of a wire, insulation, seamless bellows, braided steel conduit, and a protective cover. The igniter consists of an electrode enclosed in a ceramic and steel housing. The spark occurs between the electrode and a lip on the housing. The bell housing contains the electrical connector assembly and a tube used for pressurizing the cable. The electrical connector assembly is insulated, to prevent shorting between the spark exciter and the bell housing. The cables are pressurized with gaseous nitrogen, to prevent breathing of moisture and to inhibit the possibility of internal glow discharge (corona) during operation at high altitudes (near vacuum conditions). During engine start, the spark exciters transform 28 vdc (nominal) into 27,000 ±3,000 volts that discharge across the igniter gap at a minimum rate of 40 sparks per second. The spark ignites the propellants to initiate combustion in the gas generator and the thrust chamber.

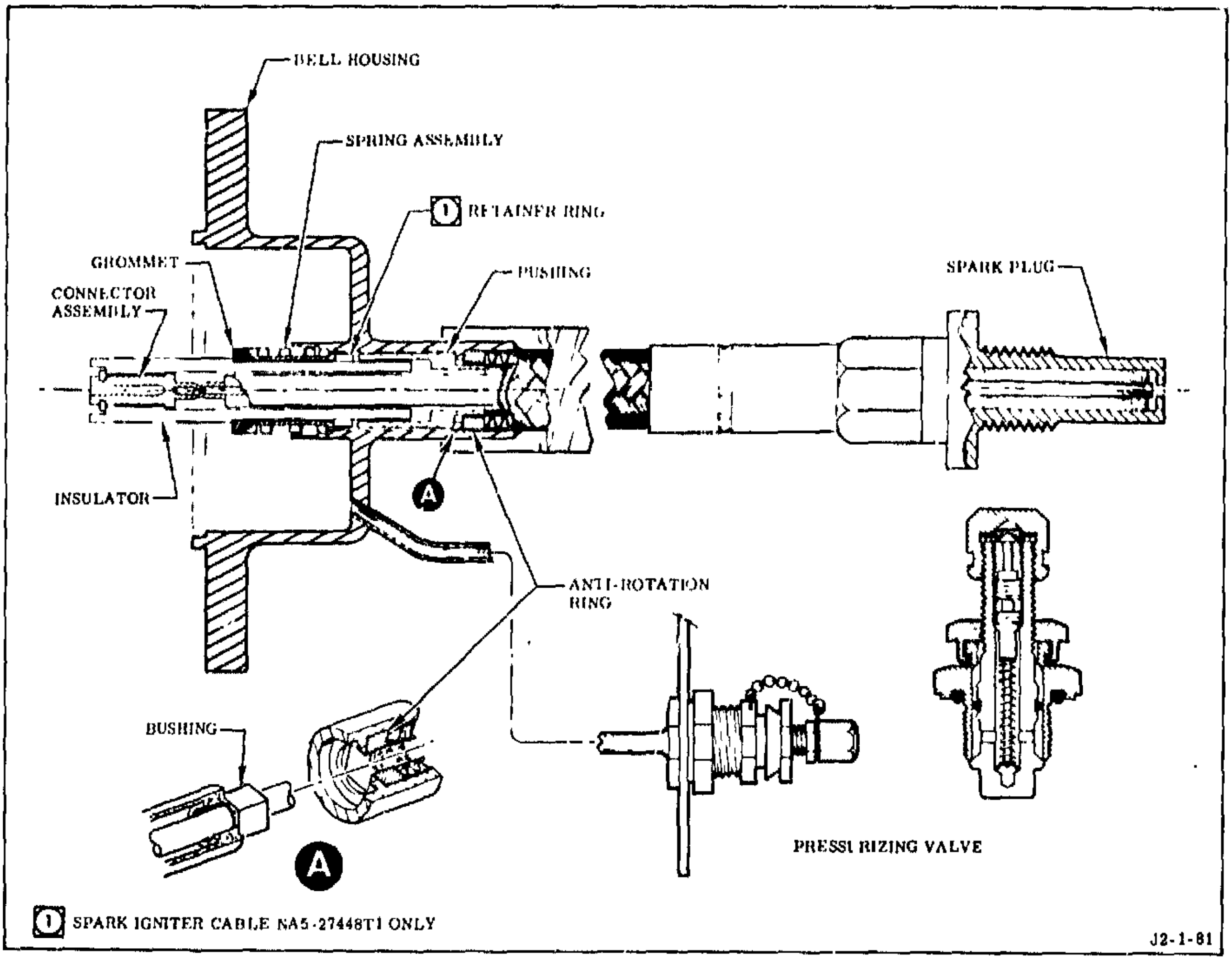

Figure 1-33. Spark Igniter Cable Assembly

1-82. IGNITION DETECTOR PROBE.

1-83. The ignition detector probe (figure 1-34) detects ignition in the augmented spark igniter chamber and sends a positive override signal to the electrical system. The probe is a fusible, wire-link detector that is inserted into the augmented spark igniter combustion zone. When the wire link is burned off by the ignition flame, the resultant resistance change unbalances a bridge-type circuit in the electrical system, to produce an ignition-complete signal. Engine cutoff will occur if an ignition-complete signal is not received before expiration of the ignition-phase timer. The ignition detector probe is used for static test only. For launch, a dummy probe, connected to the ignition detector probe electrical connector, produces an ignition-complete signal at all times.

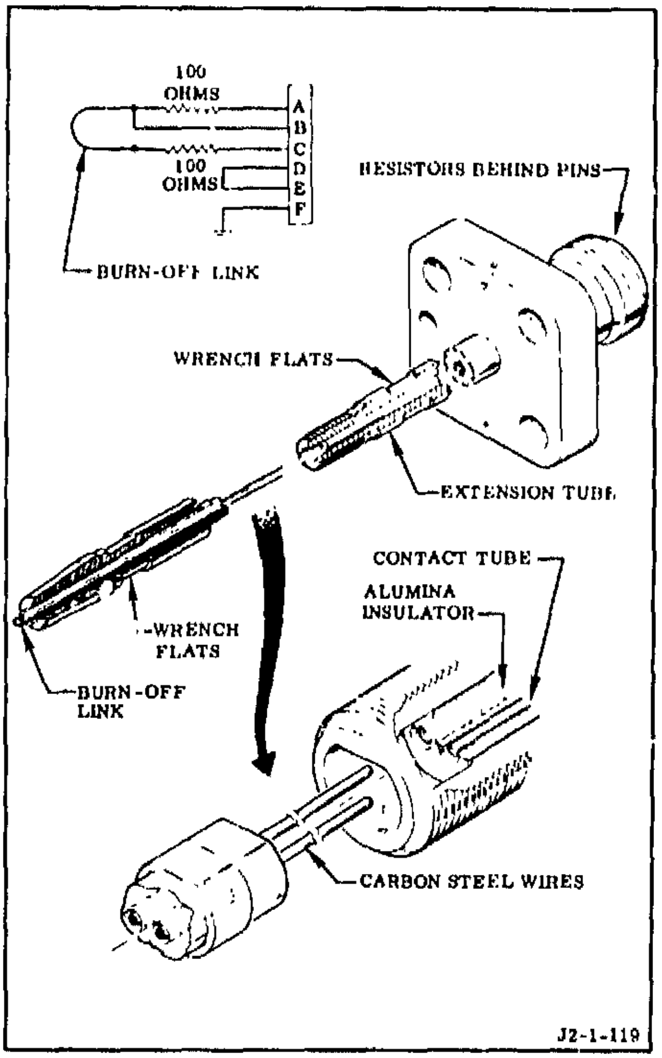

Figure 1-34. Ignition Detector Probe

1-84. CONTROL SYSTEM DESCRIPTION.

1-85. The control system provides the electrical control and the energy for valve movement and functions as an integral electro-pneumatic control system to establish valve actuation relationships. The pneumatic portion of the system consists of a helium tank that stores the helium supply; a helium regulator assembly (pneumatic control package) that controls the helium; a fast shutdown valve that speeds up the venting of the gas generator control valve; an accumulator that provides an emergency source of helium during engine operation; two sequence valves, used for valve actuation sequencing; orifices and check valves, used for individual valve timing and for directing gas flow; and the necessary plumbing to join the components into a working system. The electrical portion of the system comprises the electrical control assembly that performs the necessary sequencing and timing functions required to operate the engine; the armored harness that electrically connects the electrical control assembly to the stage and the engine components; and the mainstage OK pressure switches that monitor oxidizer pressure downstream of the main oxidizer valve.

1-86. HELIUM TANK.

1-87. The helium tank (figure 1-25) is located inside the start tank and consists of a 1,000-cubic-inch sphere for storing helium. It has sufficient supply to support two engine runs. The tank is initially filled from a ground source. On engine restart missions, the helium tank can be refilled in flight from a helium supply source in the SIVB stage.

1-88. HELIUM COVER AND FILL-CHECK VALVE.

1-89. The helium cover and fill-check valve (figure 1-35) are mounted on the start tank. The valve is a poppet-type check valve, spring-loaded to the closed position. The cover seals the tank and provides porting for the helium inlet and outlet, a mount for the fill-check valve and the start tank temperature transducer, and a connect point for securing the start tank to the thrust chamber. The fill-check valve poppet opens under helium fill pressure and allows flow of helium gas from the customer connect line into the helium tank. When helium pressure in the helium fill customer connect line is vented, the spring moves the poppet to the closed position and prevents reverse flow of helium from the tank.

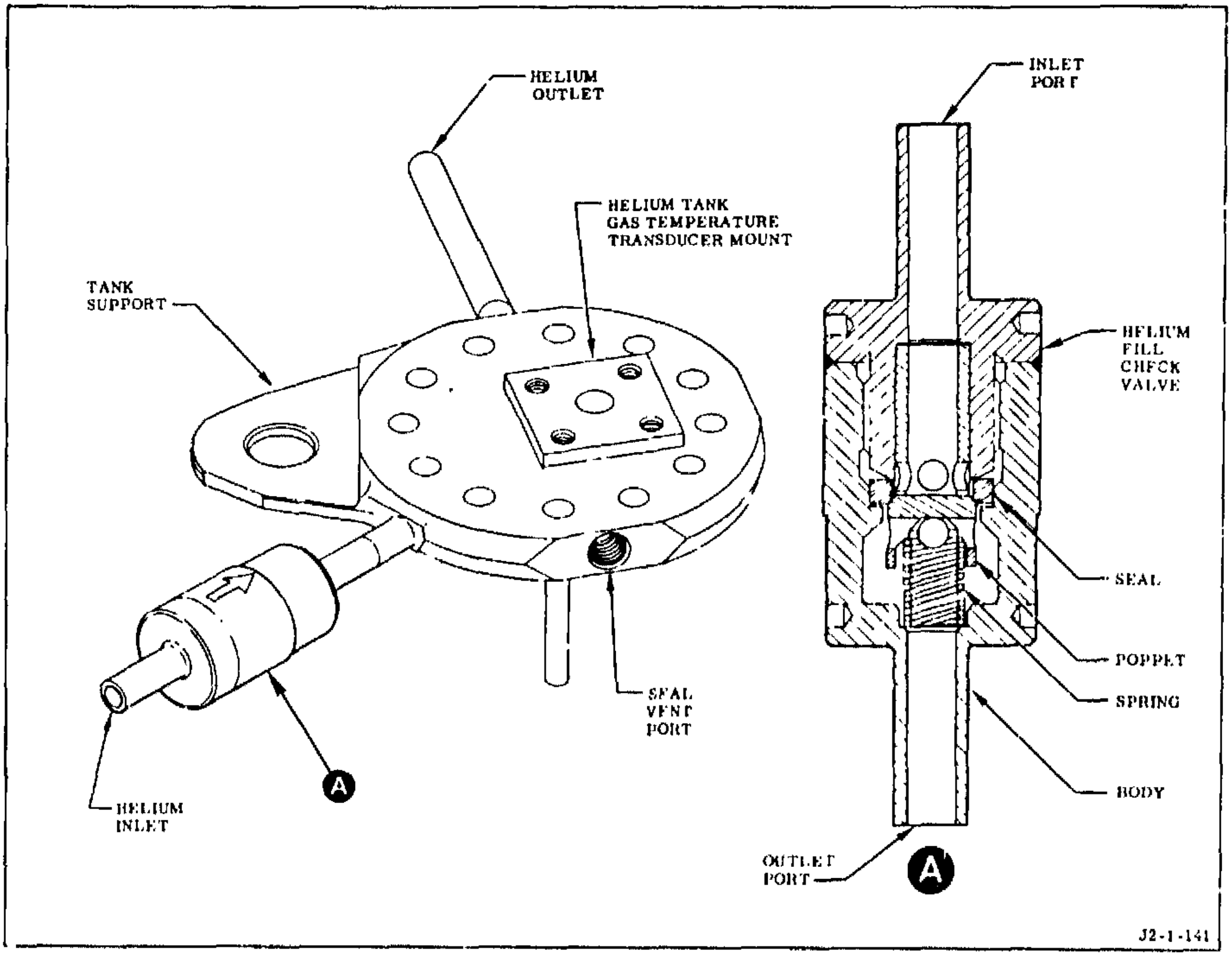

Figure 1-35. Helium Cover and Helium Fill-Check Valve

1-90. HELIUM REGULATOR ASSEMBLY (PNEUMATIC CONTROL PACKAGE).

1-91. The helium regulator assembly (figure 1-36) regulates and directs the flow of helium to all pneumatically operated valves. The assembly consists of the helium regulator that has three regulator assemblies and a low-pressure relief valve, a high-pressure relief valve, four control valves, an accumulator check valve, and a series of filters.

1-92. HELIUM REGULATOR. The helium regulator (figures 1-37 and 1-38) reduces the helium pressure from the helium tank to the required pressure for engine operation. The regulator consists of a bleed regulator, a main regulator, a control regulator, and a low-pressure relief valve. Helium pressure enters the regulator through a filter and is directed to the bleed regulator inlet. Helium passes the the ball seat and flows into a chamber that is sealed off by a diaphragm. This chamber has an exit to the helium control valve and the helium tank emergency vent control valve. The helium pressure builds up in the diaphragm chamber, overcomes spring loading pressure, moves the diaphragm and nozzle rod to close the ball seat that stops the incoming flow of helium. As helium exits the diaphragm chamber, pressure decays and allows spring tension to unseat the ball, permitting more helium to enter the regulator. The shuttling of the bleed regulator will continue at a rate that depends on the helium flow out of the exit port. If the flow is constant, the ball-seat will assume a flow-restricting position that will maintain a pressure of approximately 450 psi in the diaphragm chamber. If pressure exceeds 500 psi in the diaphragm chamber, the nozzle is unseated and pressure is vented through the nozzle into the spring cavity and out a vent port check valve.

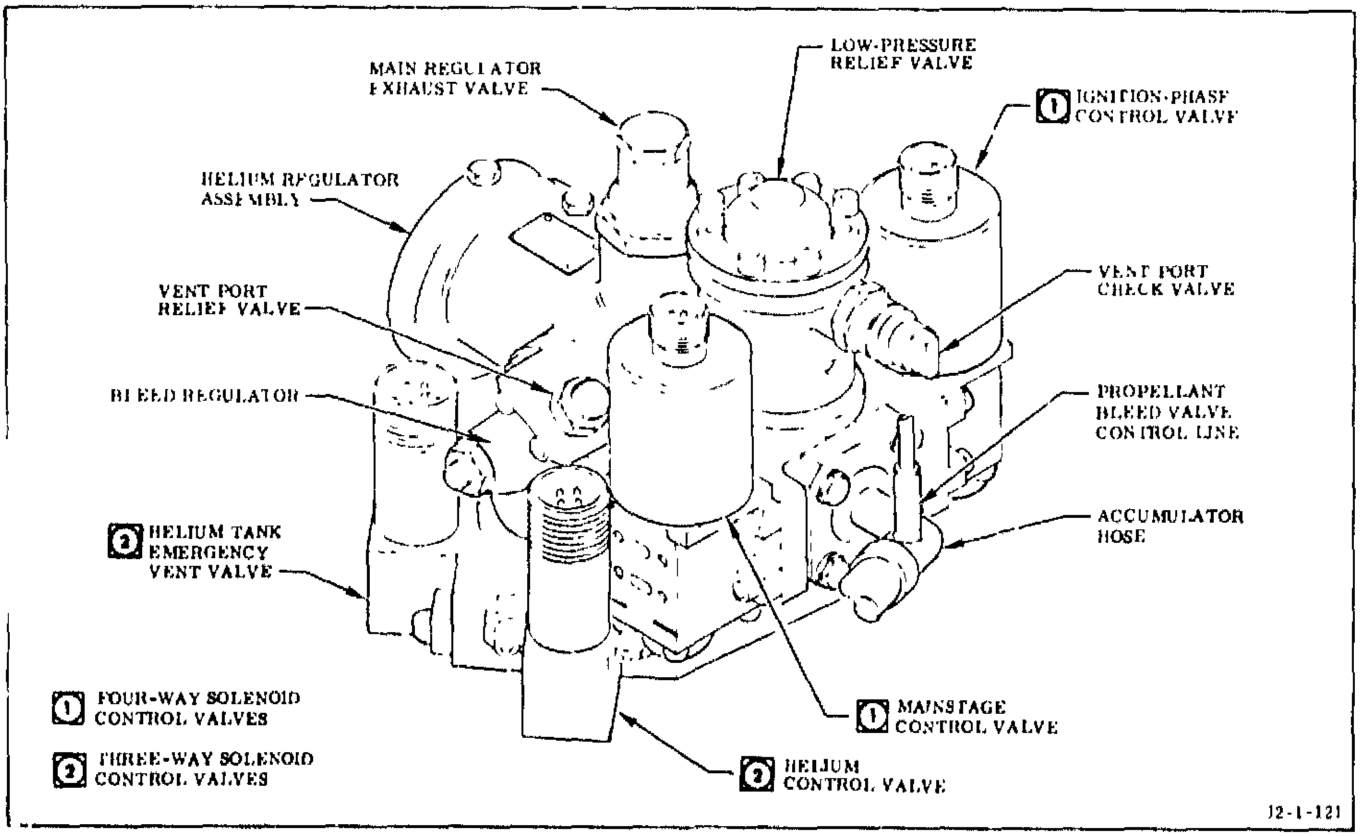

Figure 1-36. Helium Regulator Assembly

1-93. Actuation of the helium control valve routes helium to the dome side of the main regulator diaphragm and to the control regulator. The pressure on the dome side of the main regulator diaphragm overcomes spring tension to unseat the ball; this allows gas to be routed to the spring side of the diaphragm and through the accumulator check valve to the engine components. Pressure on the spring side of the diaphragm, aided by spring tension, overcomes the pressure on the dome side of the diaphragm and retracts the diaphragm to allow the ball to reseat. If pressure on the spring side of the diaphragm drops below 400 psi, the pressure on the dome side unseats the ball and the 400 psi is restored. This action is repeated to maintain a constant regulator outlet pressure. The control regulator maintains a reference pressure of approximately 410 psi on the dome side of the main regulator diaphragm and, by adjustments to this reference pressure, controls the outlet pressure of the main regulator at approximately 400 psi. This is done by directing helium outlet pressure from the main regulator to the diaphragm cavity of the control regulator, where it is balanced against spring tension. When the main regulator outlet pressure exceeds 400 psi, the spring in the control regulator is further compressed, allowing main regulator dome reference gas pressure to unseat the control regulator ball and poppet and allowing the reference gas to bleed into the control pressure side of the control regulator. A drop in dome reference pressure results in a lower main regulator outlet pressure that allows the spring in the control regulator to reseat the ball and poppet. This action is repeated to control the main regulator output.

1-94. The low-pressure relief valve is a pilot-operated relief valve. Helium pressure entering the valve exerts force against both the bottom and top of the piston. This pressure and spring pressure keep the piston seated and the vent port closed. If there is a pressure surge or a regulator malfunction, the excessive pressure overcomes the spring tension and piston pressure loading to force the pilot poppet upward. This action vents the pressure acting against the top of the piston, and pressure against the bottom of the piston drives the piston upward, opening the vent port. When the excess pressure is relieved, spring pressure returns the pilot poppet and piston to their original positions.

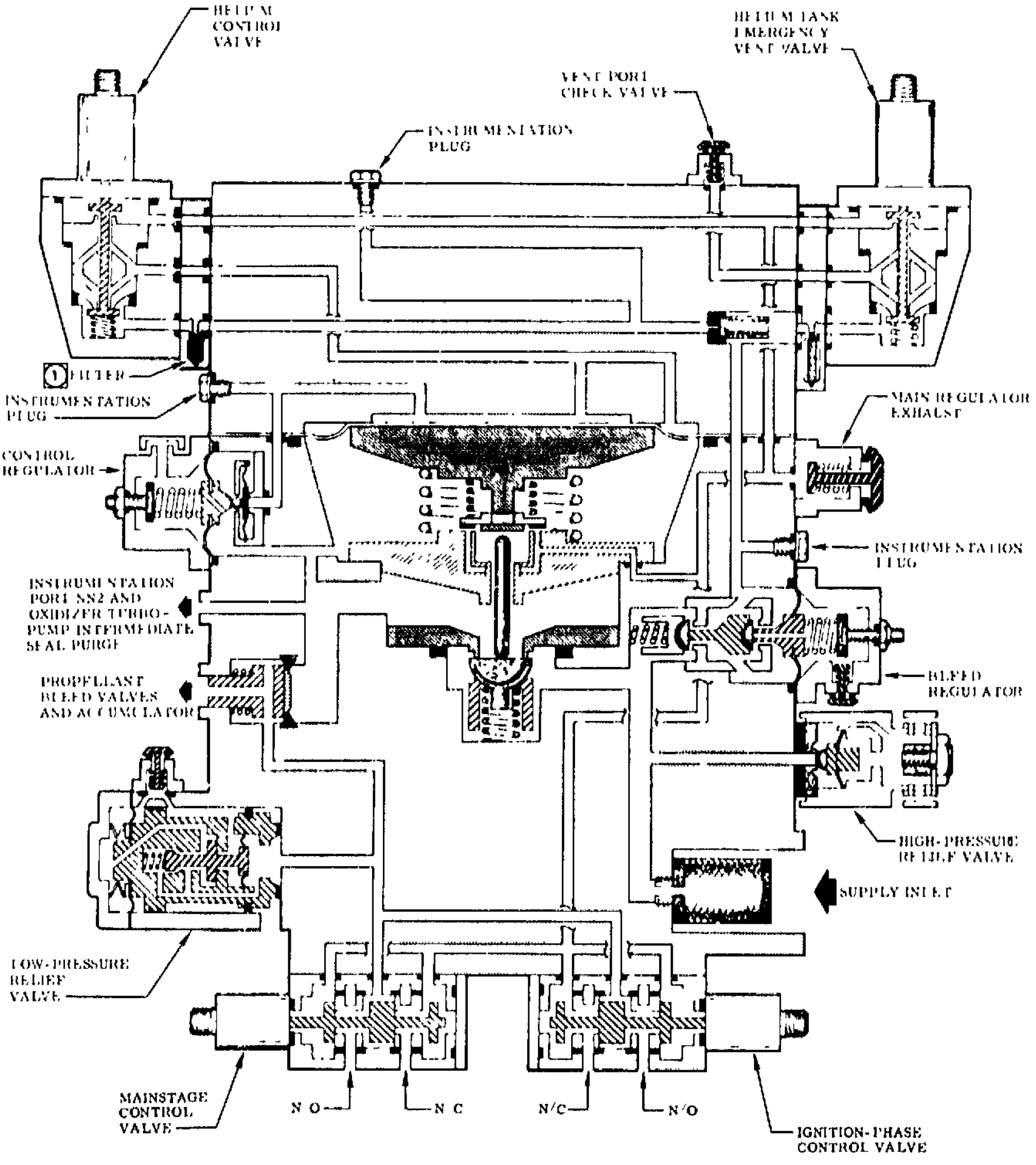

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Figure 1-37. Helium Regulator Schematic

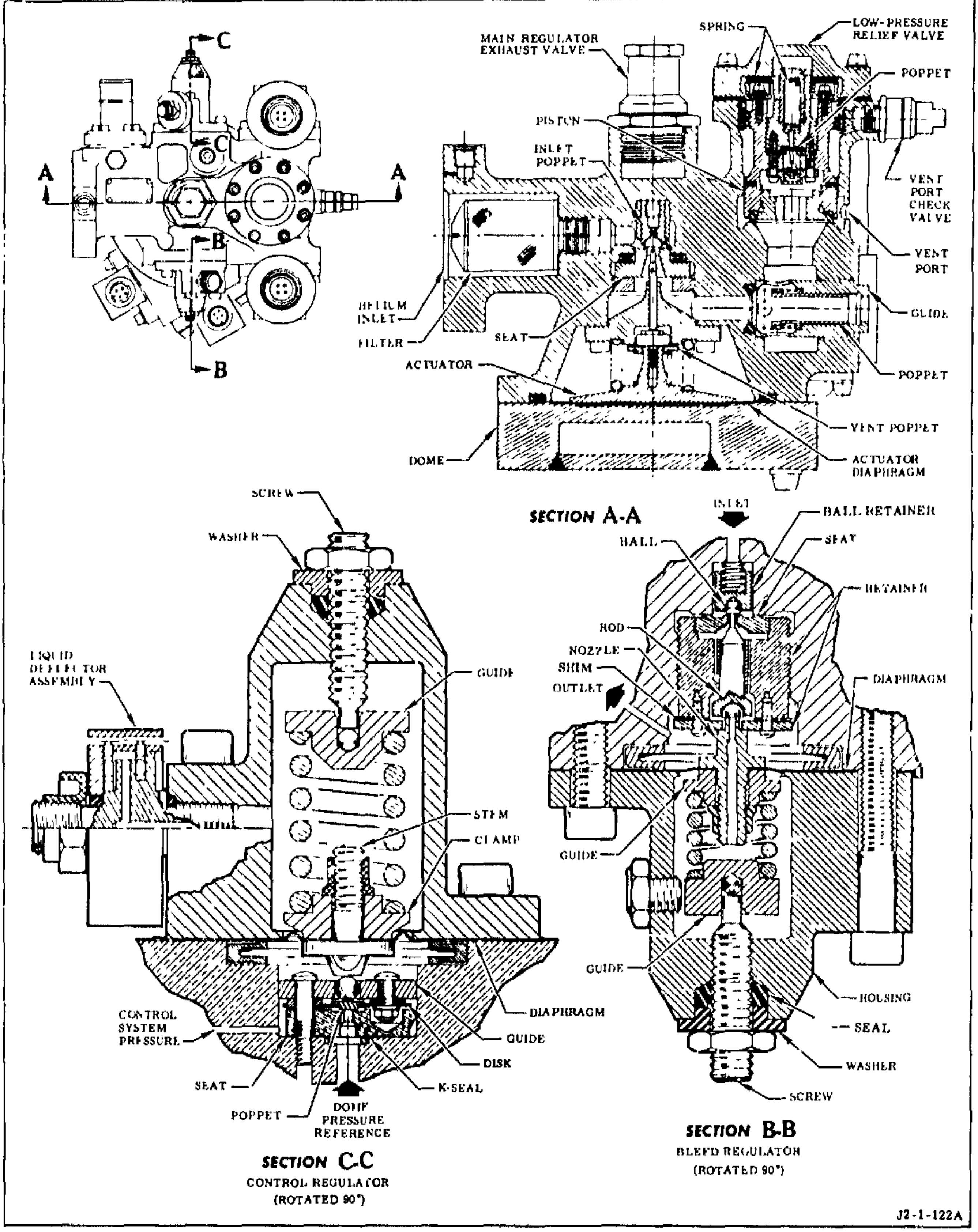


Figure 1-38. Helium Regulator

1-95. HIGH-PRESSURE RELIEF VALVE. The high-pressure relief valve (figure 1-39) prevents overpressurization of the helium supply system. The valve is a spring-loaded, ball-type, relief valve that starts to open at a pressure of approximately 3,800 psi, is fully opened at approximately 4,000 psi, and reseats at approximately 3,500 psi. The spring holds the retainer against the ball, and the ball seals the inlet in the seat. Excessive helium pressure compresses the spring, unseats the ball, flows around the ball, and is routed overboard through the valve outlet. The valve has a protective hood to prevent the entrance of moisture.

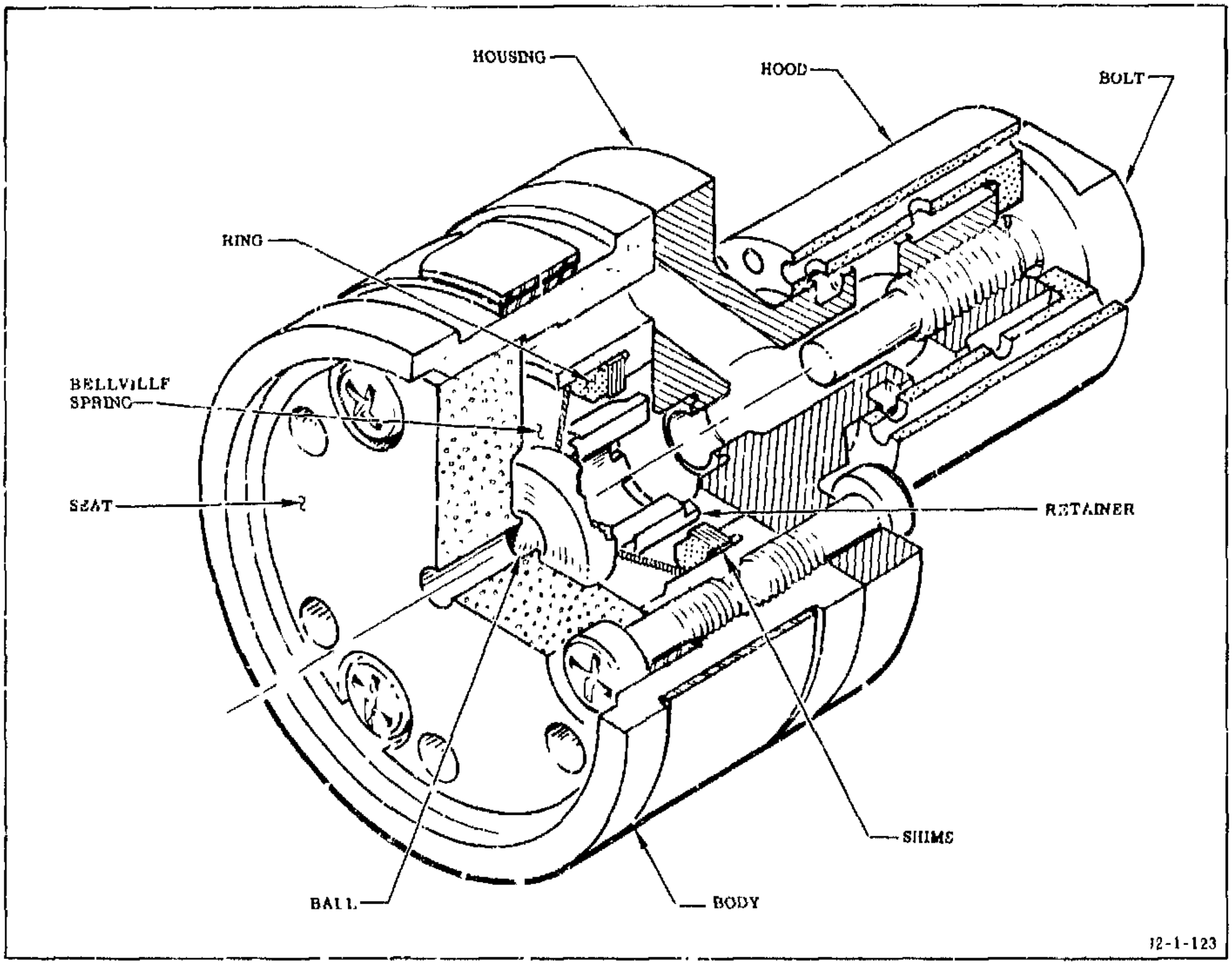


Figure 1-39. High-Pressure Relief Valve

1-96. FOUR-WAY PNEUMATIC (START TANK DISCHARGE VALVE, IGNITION-PHASE, AND MAINSTAGE) CONTROL VALVES. The mainstage, ignition-phase, and start tank discharge valve control valves (figure 1-40) are four-way, electrically operated, direct-acting solenoid valves in which opening and closing functions are arranged so that one is venting while the other is pressurizing. The start tank discharge valve control valve directs pressure to the closing or opening control ports of the start tank discharge valve. The ignition-phase control valve, when energized, supplies opening pressure to the main fuel valve and augmented spark igniter valve, and gas generator control valve opening pressure and oxidizer turbine bypass valve closing pressure to the main oxidizer valve sequence valve. The mainstage control valve, when energized, supplies opening pressure to the main oxidizer valve and shuts off thrust chamber oxidizer injector and gas generator oxidizer purges. When the solenoid is energized, the piston moves the poppet, and the normally closed port is opened, allowing helium to flow through the control valve. At the same time, pressure supply to the normally open port is blocked off and this port is vented. When the solenoid is deenergized, the piston reseats, the trapped pressure is vented, and helium flows through the normally open port.

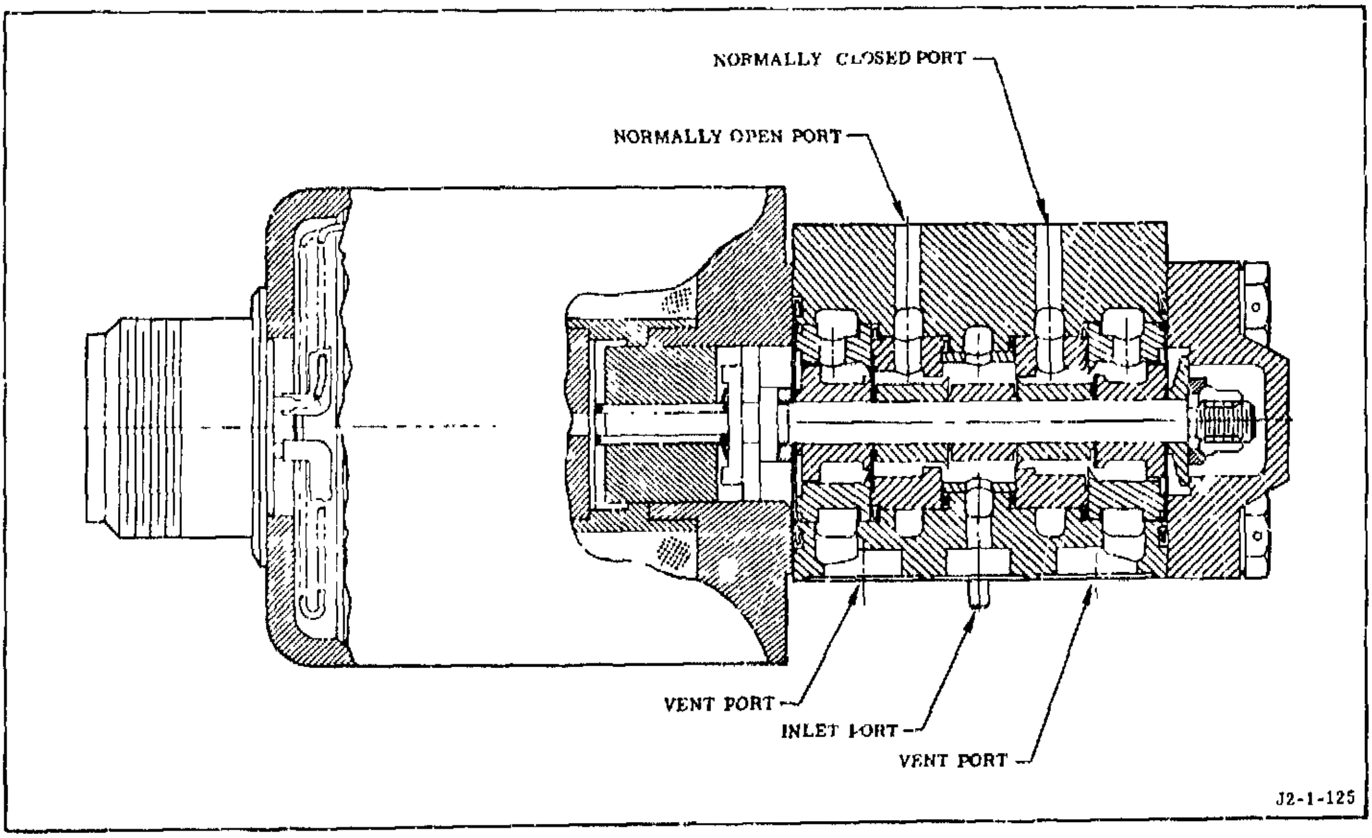


Figure 1-40. Four-Way Pneumatic (Start Tank Discharge Valve, Ignition-Phase, and Mainstage) Control Valves

1-97. THREE-WAY PNEUMATIC (HELIUM, HELIUM TANK EMERGENCY VENT, AND MIXTURE RATIO VALVE) CONTROL VALVES. The helium control, helium tank emergency vent control valves (figure 1-41), and the mixture ratio valve control valve are three-way, electrically operated, direct-acting, normally closed solenoid valves. The helium control valve directs helium pressure to the main regulator and the control regulator. The helium tank emergency vent control valve provides an alternate means of venting the helium tank. The mixture ratio control valve solenoid valve is functionally identical to the helium control and helium tank emergency vent solenoid valves. This valve, when energized by a stage signal, routes helium pressure to the mixture ratio control valve to move the valve to the low engine mixture ratio position. When the solenoid is deenergized, the outlet port is connected to the vent port. When the solenoid is energized, the armature shuttles the poppets to the open position, allowing flow from the inlet port to the outlet port and closing the flow path to the vent port.

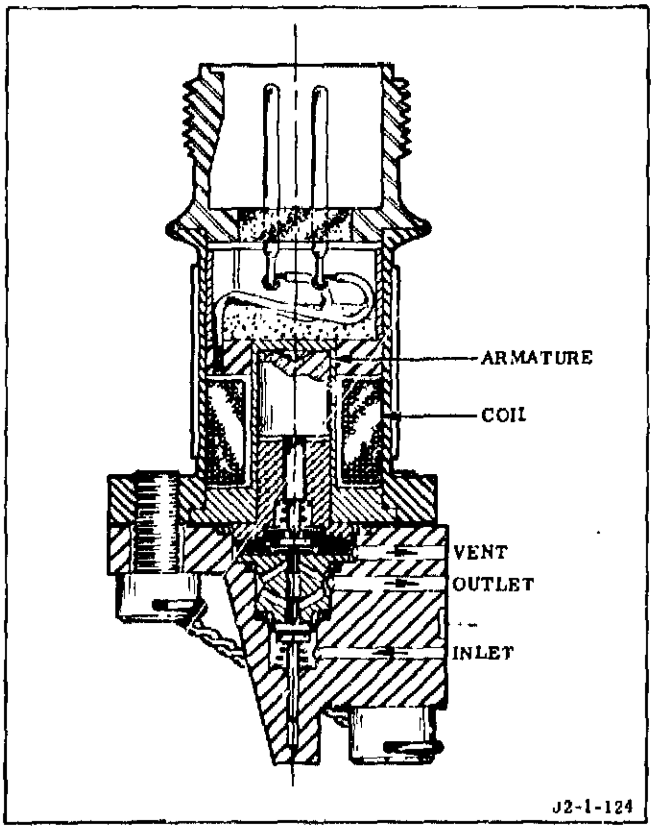


Figure 1-41. Three-Way Pneumatic (Helium, and Helium Tank Emergency Vent) Control Valves

1-98. PNEUMATIC ACCUMULATOR.

1-99. The pneumatic accumulator provides the necessary gas volume for the safe operation and shutdown of the engine in the event of a loss of high-pressure helium supply. The pneumatic accumulator is an integral part of the primary instrumentation package that is enclosed within an outer shell and cover. The volume between the primary instrumentation package and the outer shell and cover serves as the pneumatic accumulator.

1-100. FAST-SHUTDOWN VALVE.

1-101. The fast-shutdown valve (figure 1-42) vents the gas generator control valve opening control pressure at engine shutdown. The valve is a two-position, normally closed, poppet valve that is actuated to the open position by helium pressure. At engine start and run, helium pressure is supplied to the inlet port where it is routed to the top of the upper control diaphragm. This pressure, with spring tension, maintains the valve in the close position. At engine cutoff, helium pressure is routed to the valve control port, enters the control port, and acts upon the diaphragm to overcome the force of the piston spring and any remaining pressure at the top of the diaphragm, moving the piston to the open position.

1-102. RESTRICTOR CHECK VALVES.

1-103. The restrictor check valves (figure 1-43) are orificed, poppet-type, and spring-loaded to the closed position. The oxidizer turbine bypass valve opening time is controlled by a check valve at the main oxidizer valve sequence valve outlet port. The start tank discharge valve closing time is controlled by a check valve at the valve opening control port. Application of helium pressure overcomes the spring tension and unseats the poppet, allowing helium to flow to the extent determined by the orifice plug or valve poppet orifice. When pressure is decreased, the spring tension overcomes the decaying pressure and reseats the poppet. When the valve is closed, reverse flow is restricted through the orifice.

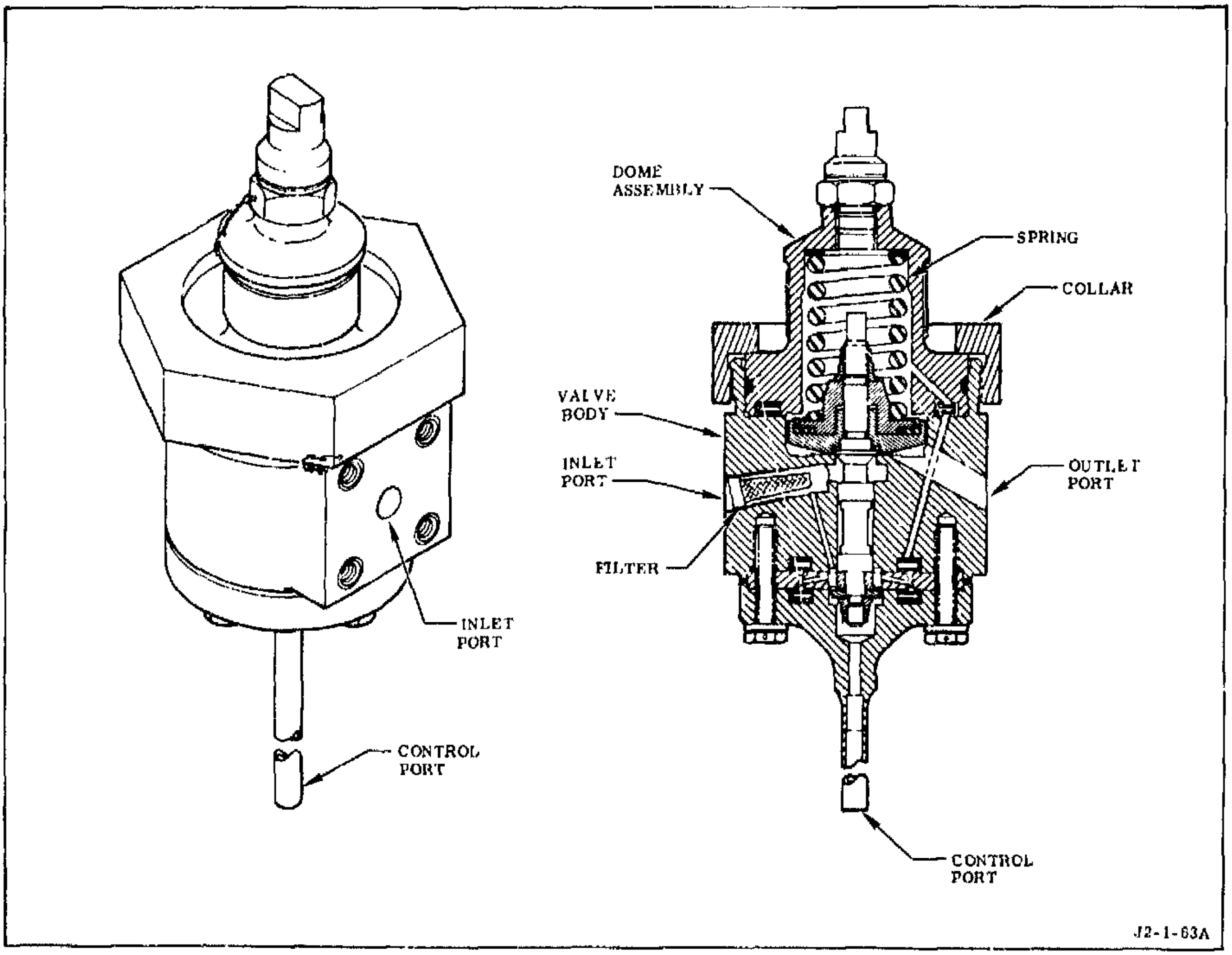


Figure 1-42. Fast-Shutdown Valve

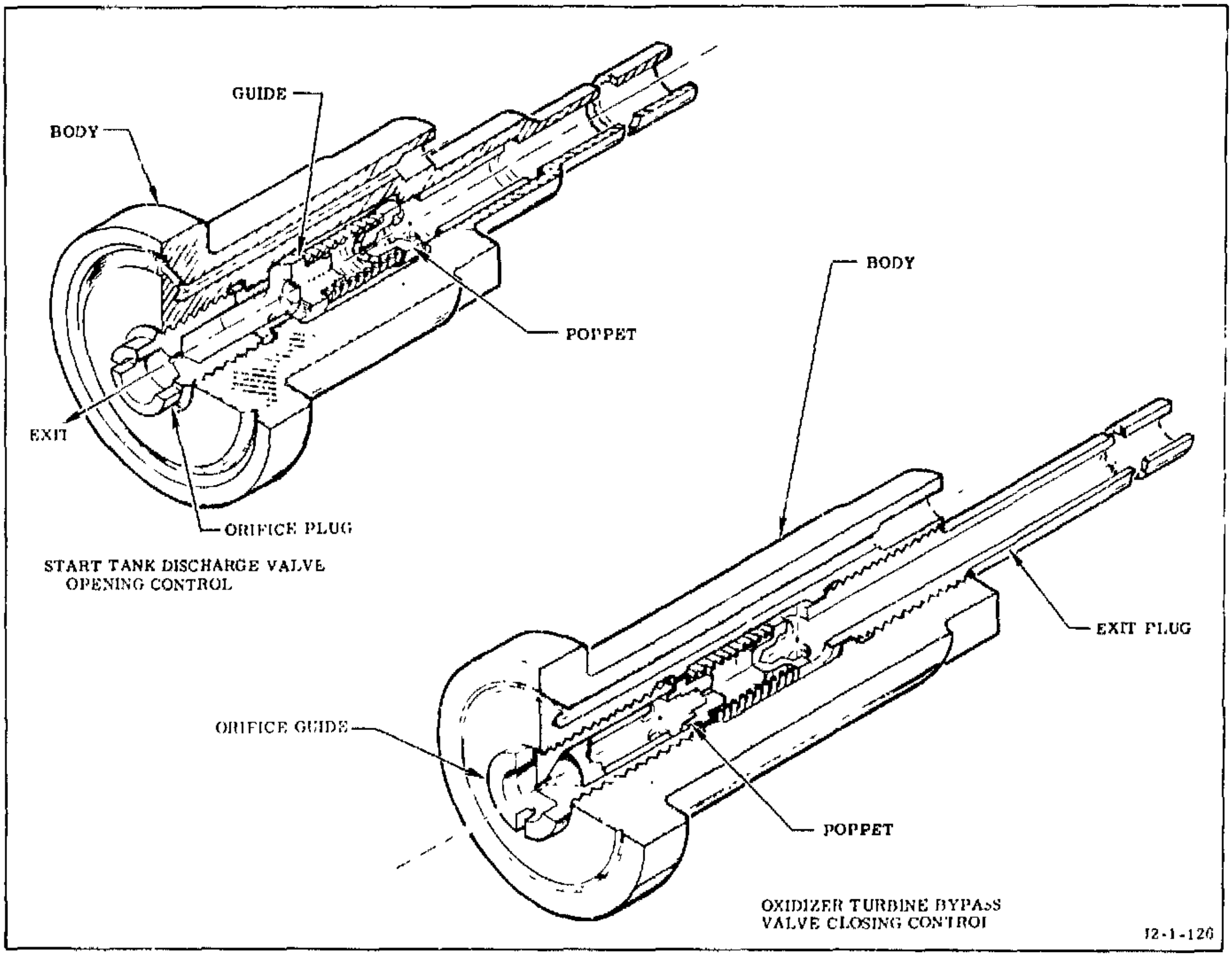


Figure 1-43. Restrictor Check Valves

1-104. ELECTRICAL CONTROL ASSEMBLY.

1-105. The electrical control assembly (figures 1-44 and 1-45) is a sealed, dome-shaped, pressurized control assembly containing spark exciters and sequence controller circuitry. The unit is self-contained and requires only dc power and external engine start, mainstage enable, and cutoff signals to operate. Additional signals are provided to the stage to allow monitoring of the engine condition at significant points of engine operation. The system also has the capability to actuate individual components through checkout equipment. The control system will automatically reset itself after engine operation, to provide multiple engine restart capability, by using the engine-ready signal as a cutoff-reset function. However, there may be conditions where engine-ready is not obtained after a firing, and a restart attempt is desired. To provide for this possibility, an engine-ready bypass provision is incorporated to allow cutoff-reset from the stage.

1-106. The six major printed-circuit boards that have the necessary solid-state switching elements are: (1) the engine monitor board, which monitors engine and ECA conditions before commit start; (2) the engine start board, which receives stage commit start signal, locks in and provides for helium control valve energization, and has redundant helium deenergize timers for cutoff; (3) the spark control board, which receives a signal from the engine start board and activates the four spark exciters; (4) the valve control board, which provides power for energizing the ignition-phase, mainstage, and STDV control valves;

(5) the programmer board, which has redundant timers and a multiplex module to control energization and deenergization of the STDV control valve, energization of the mainstage control valve, and deactivation of the spark exciters; and (6) the cutoff control board, which receives a stage or engine-generated cutoff signal and deenergizes ignition and mainstage solenoids and activates the helium deenergize timer. The multiplex module on the programmer board, superimposes each redundant timer function on three of the four spark monitor output traces. The STDV delay, ignition phase, and sparks deenergize timers have a two out of three voting logic redundancy. The helium deenergize timers have parallel redundancy.

1-106A. During the pre-ignition phase of the engine start sequence, 28 vdc power is applied to the ECA sequence and ignition busses and an engine ready signal is sent from the ECA engine monitor board if: (1) the following conditions exist; K101 and K103 bus power on, electrical connectors installed, M/S OK pressure switches dropped out, OTBV open; and (2) the following signals are absent; engine start, helium control on, ignition phase control on, STDV control on, mainstage control on, ASI spark system on, GG spark system on, and mainstage OK. A signal is also sent to the cutoff board to ensure cutoff reset.

1-106B. After the stage commit start signal is initiated, the ECA sequencer engine start board accepts the start signal and then provides for a lock-in circuit. Four sequencing events occur at this time: (1) power is applied to the spark control board and spark excites are activated; (2) the helium control valve is energized; (3) power is applied to the valve control board to energize the ignition phase control valve; and (4) a signal is sent to the programmer board to activate the redundant, one second STDV delay timers. A stage supplied mainstage enable signal and the output signal from the STDV delay timers activate an "and" gate in the programmer board, which activates the redundant 0.45-second ignition phase control timers. At the same time, through an "and" gate in the valve control board the STDV control valve is energized. An output signal from the ignition phase timers is the completion of ignition phase and start of mainstage.

101-6C. Output from the programmer board ignition phase timers deenergizes the STDV control valve, activates the redundant 3.3-second sparks deenergize timers, and energizes the mainstage control valve. The lock-in circuits for both ignition phase and mainstage are activated. Engine thrust build-up actuates the M/S OK pressure switches, which send an override signal to the cutoff control board (only one of two is required). An output signal from the sparks deenergize timers sends a cutoff signal from the programmer board to the cutoff control board. If an override signal from the M/S OK pressure switches is present, the cutoff "and" gate is not activated. The output signal from the sparks deenergize timer also negates the engine start logic. Because of the lock-in circuits, the engine control valves are not affected. However, the spark control logic gates are negated causing power to be removed from the spark exciters. An engine steady burn Condition is now achieved.

1-106D. The engine cutoff signal may be programmed (from the stage or may be generated by both of the M/S OK pressure switches not picking up. In either case, the signal is directed to the cutoff control board where it is locked-in by "or" and "and" gates. The cutoff control board output signal is sent to the engine start and valve control boards. On the engine start board, the one-second helium deenergize timers are activated and engine start logic gates are negated. Power to the sparks and valve-solenoid control circuits is lost. On the valve control board, ignition phase and mainstage "and" and "or" gates are negated breaking the holding circuit, and the control valves deenergize. If activated at this time (as during engine start), the start tank discharge "and" and "or" gates are negated and the STDV control valve deenergizes. An output from the helium deenergize timers negates engine start board "and" and "or" gates and the helium control valve is deenergized.

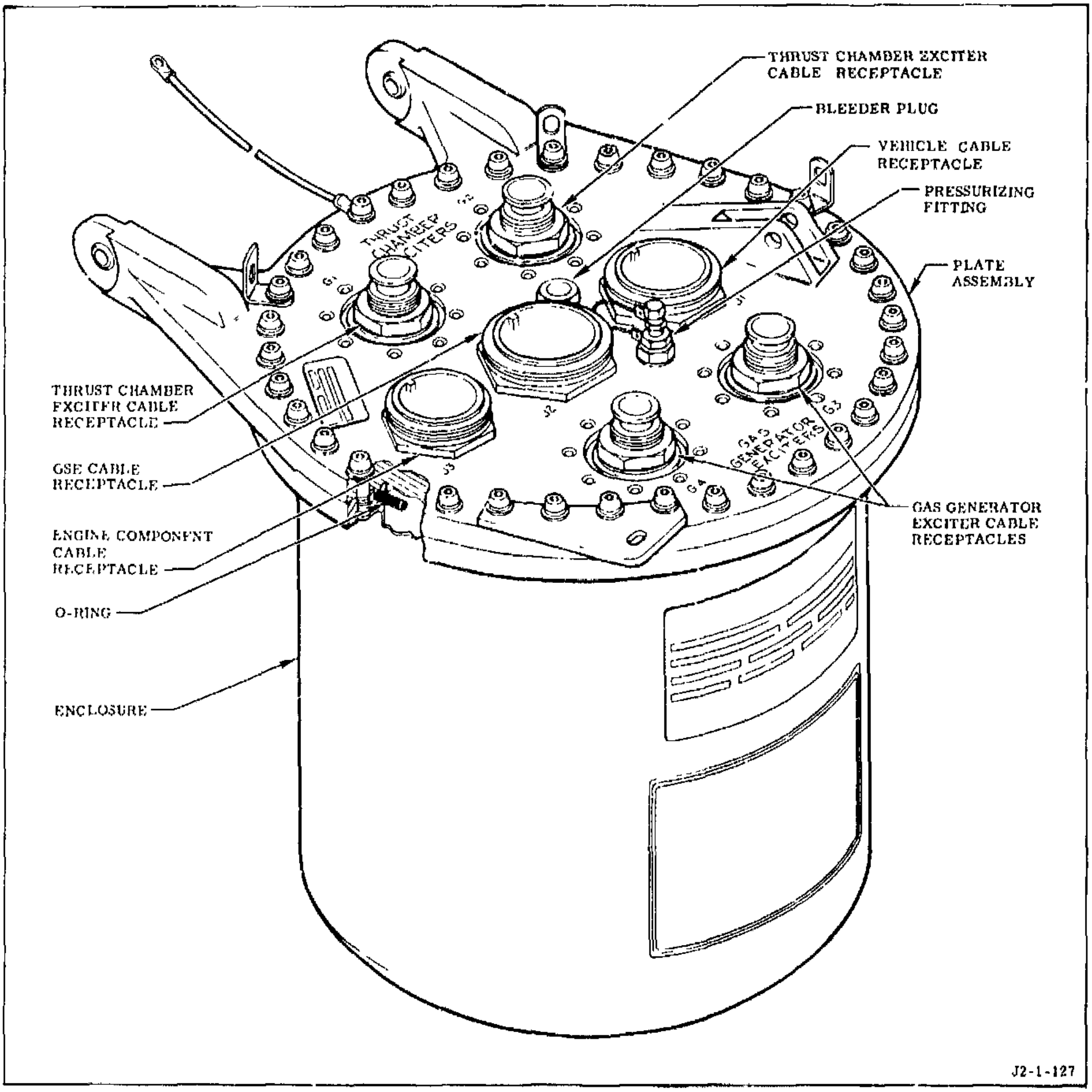


Figure 1-44. Electrical Control Assembly

1-107. ARMORED HARNESS.

1-108. The armored harness electrically connects the electrical control assembly to the stage and to the electrically controlled engine components. The harness is made up of Teflon-insulated wires that are wrapped in a layer of Mylar tape, sleeved in a silicone rubber tube, and sheathed in two layers of nickel-plated copper wire braid. The silicone rubber tube is for thermal protection, and the wire braid is for protection against abrasion and radio-frequency interference. Mylar tape is used to aid installation of the silicone rubber tube. A compound of polyurethane is overmolded at the Y-joints and connectors to secure and cover the wire braid pigtails. The overmolds are not intended to be moisture-sealing devices. When the harness is installed on the engine, a thermo-protective boot is installed over each connector.

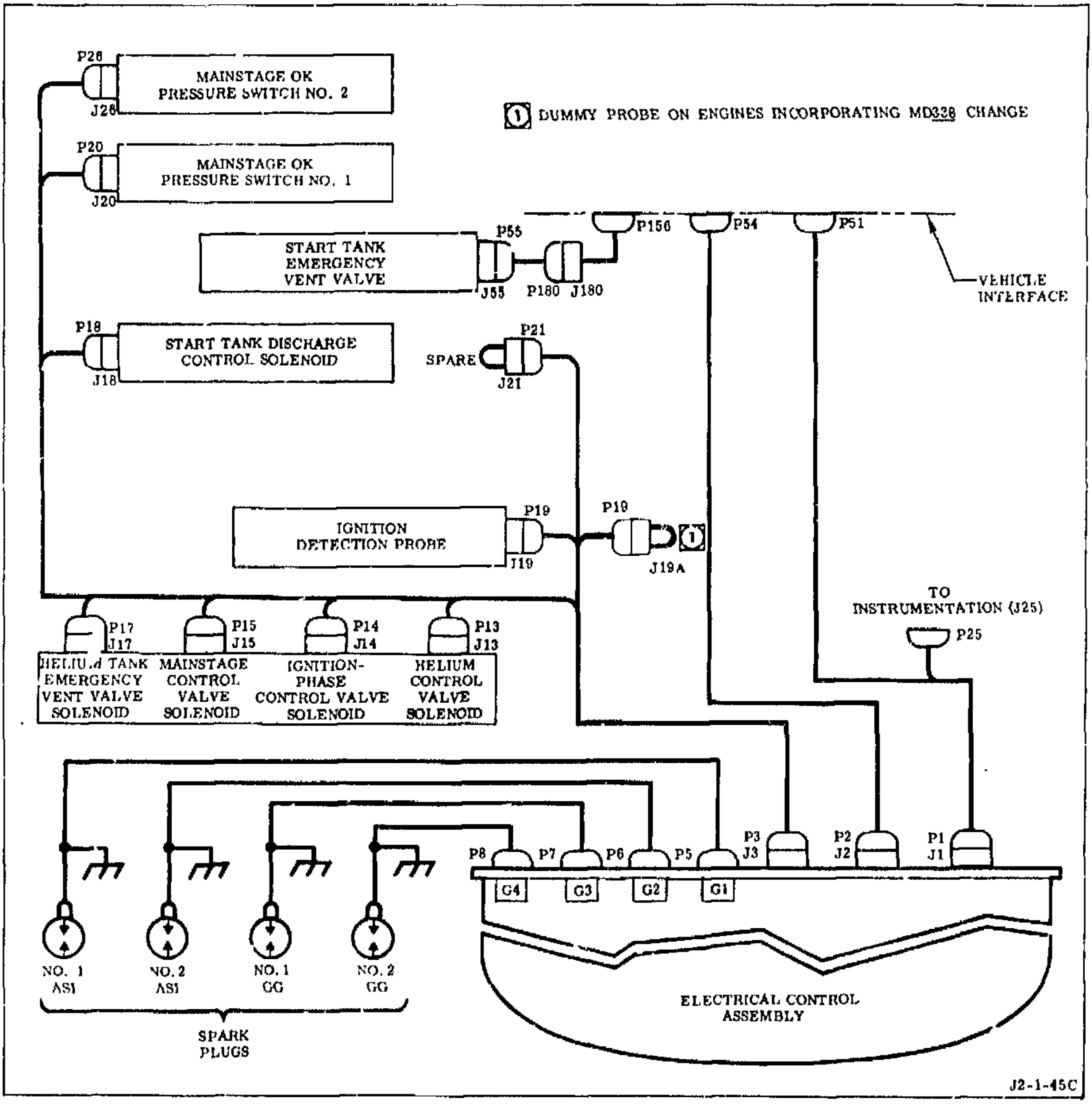


Figure 1-45. Electrical Block Diagram

1-109. MAINSTAGE OK PRESSURE SWITCHES.

1-110. The mainstage OK pressure switches monitor oxidizer injection pressure to determine proper engine mainstage operation. Mainstage OK pressure switches have an inlet port, a checkout port, two diaphragms, toggle blades, a toggle spring, a housing, and an electrical switch and connector. Pressure entering either port acts upon a diaphragm, linked to the electrical switch through the toggle spring and toggle blades. During engine start, the switches must pick up before deenergization of the spark ignition system or engine cutoff will be initiated. Pickup of either pressure switch will block initiation of engine cutoff. During engine operation, engine cutoff will be initiated whenever dropout of the switches is caused by deterioration of oxidizer injection pressure. Both switches must drop out for cutoff to be initiated. A line connected to the checkout port of each pressure switch is routed across the engine gimbal to the customer connect panel. The switches are function-tested by applying pressure to this line.

1-111. PURGE SYSTEM DESCRIPTION.

1-112. The engine is purged before engine start to remove moisture-laden air, clear combustion areas of any propellants, and maintain an inert environment. During engine operation, the turbopump seal areas are purged to keep any propellant leakage from reaching areas containing turbine gas products. After engine run, purging clears combustion products and prevents moisture accumulation. The purge system comprises a purge control valve that permits or stops the helium purge to the thrust chamber and gas generator oxidizer injectors; an oxidizer turbopump intermediate seal purge check valve and a fuel turbopump primary seal drain check valve that maintain correct pressure in the seal cavities; an oxidizer injector purge check valve that prevents oxidizer from reverse flowing into the helium system; and purge check valves (thrust chamber fuel jacket purge, gas generator fuel and oxidizer purge, fuel and oxidizer turbine seal purge, and fuel turbopump primary seal purge) that prevent reverse flow through the purge system during engine operation.

1-113. PURGE CONTROL VALVE.

1-114. The purge control valve (figure 1-46) starts or stops helium flow used to purge the thrust chamber and gas generator oxidizer injectors. The valve is a two-position, normally closed, poppet valve that is actuated to the open position by helium pressure. Helium pressure is supplied to the inlet port where it is routed to the top of the upper control diaphragm. This pressure, with spring tension, maintains the valve in the closed position. During operation, helium pressure enters the control port and acts upon the diaphragm to overcome the force of the spring and inlet pressure at the top of the diaphragm, and moves the seal cage to the open position.

1-115. PURGE CHECK VALVES.

1-116. The purge check valves (figure 1-47) are installed in the thrust chamber fuel jacket purge, gas generator fuel and oxidizer purge, fuel and oxidizer turbine seal purge, and fuel turbopump primary seal purge, to prevent reverse flow through the purge system during engine operation. The check valves are poppet-type valves, spring-loaded to the closed position. Helium pressure is applied from the stage pressure system or the engine helium system (gas generator oxidizer injector purge) to purge these areas, the pressure overcomes the spring tension, unseats the poppet, and allows the purge gas to flow. When purging is terminated, the pressure decays and the spring tension reseats the poppet to prevent backflow. On engines incorporating MD383 or MD384 change, a redundant purge check valve is installed downstream of the purge control valve, to prevent contaminating the pneumatic system with oxidizer if either the oxidizer injector or the gas generator oxidizer purge check valves leak.

1-117. FUEL TURBOPUMP PRIMARY SEAL DRAIN CHECK VALVE.

1-118. The fuel turbopump primary seal drain check valve (figure 1-47) is installed in the fuel turbopump primary seal drain customer connect line to maintain the proper pressure in the seal cavity. The check valve is a poppet-type valve, spring-loaded to the closed position. As pressure builds up in the fuel turbopump primary seal cavity, it overcomes the spring tension to open the poppet and allow excess pressure to vent overboard. When pressure in the seal cavity decays, spring tension reseats the valve poppet.

1-119. OXIDIZER TURBOPUMP INTERMEDIATE SEAL PURGE CHECK VALVE.

1-120. The oxidizer turbopump intermediate seal purge check valve (figure 1-47) is connected to the purge line downstream of an orifice to maintain proper purge pressure and prevent overpressurization of the intermediate seal. The check valve is a poppet-type valve, spring-loaded to the closed position. When the helium control valve is energized, helium regulator

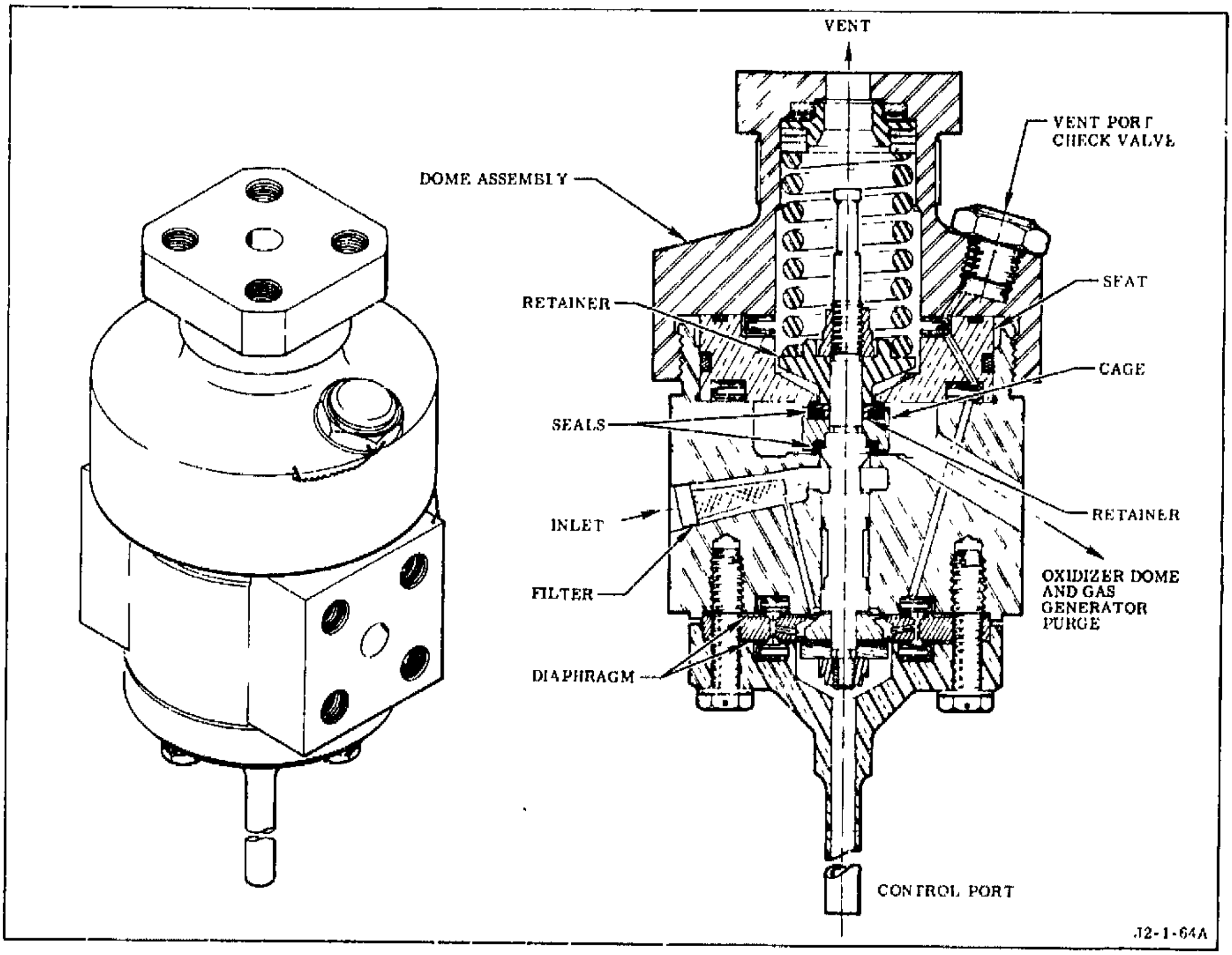


Figure 1-46. Purge Control Valve

outlet pressure is supplied to the check valve. The pressure overcomes the spring tension to open the poppet and allow excess pressure to vent overboard. When the helium control valve is deenergized, the pressure decays and spring tension reseats the valve poppet.

1-121. OXIDIZER INJECTOR PURGE CHECK VALVE.

1-122. The oxidizer injector purge check valve (figure 1-48) prevents reverse flow of oxidizer into the purge system during engine operation. The valve is a spring-loaded, normally closed, poppet check valve, located on the main oxidizer valve. The oxidizer injector purge is controlled by the purge control valve. Helium flow continues to purge the thrust chamber oxidizer injector, until the mainstage control solenoid valve is energized. At engine cutoff, the purge flows until the helium control valve is deenergized, one second after the cutoff signal.

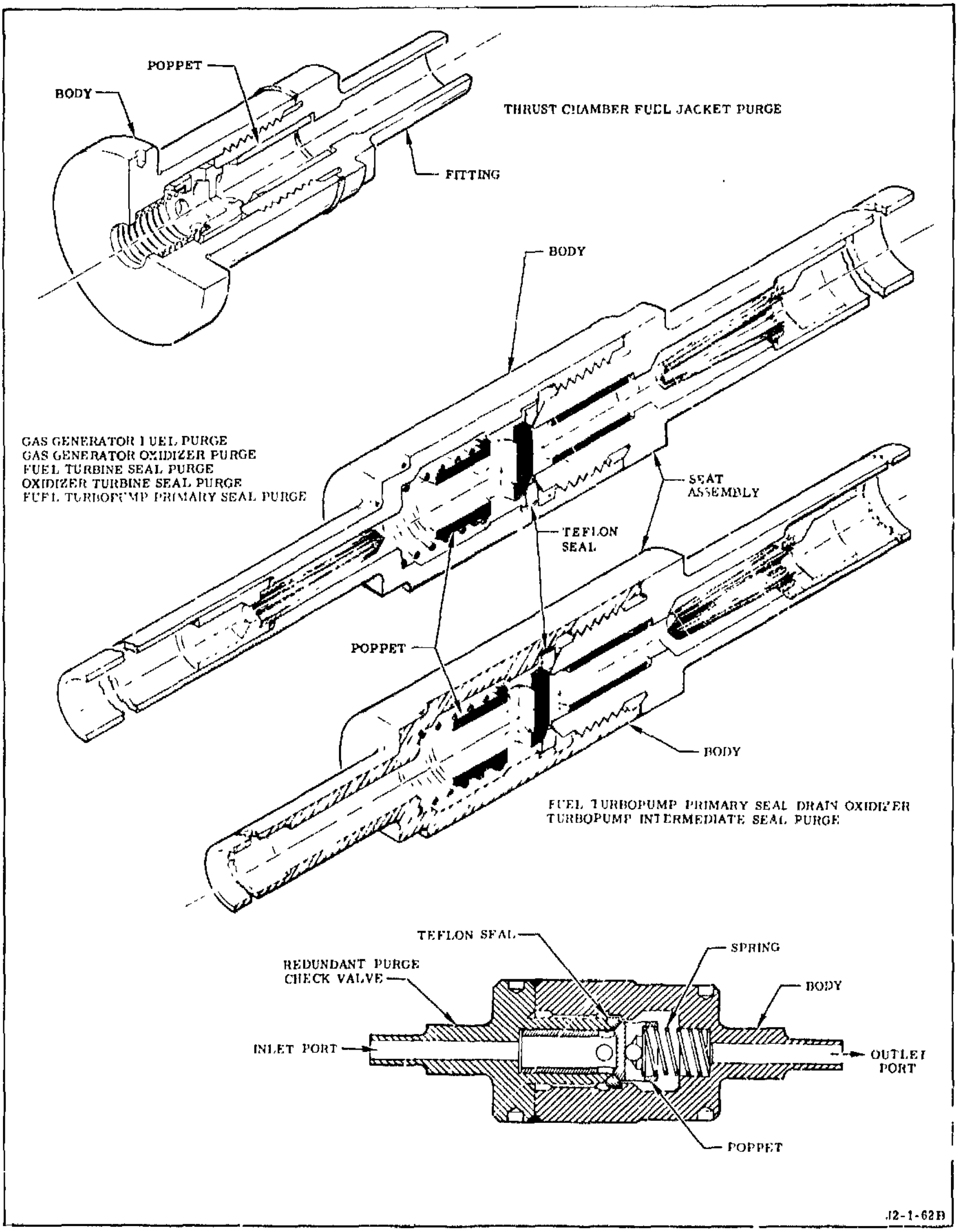


Figure 1-47. Purge Check Valves

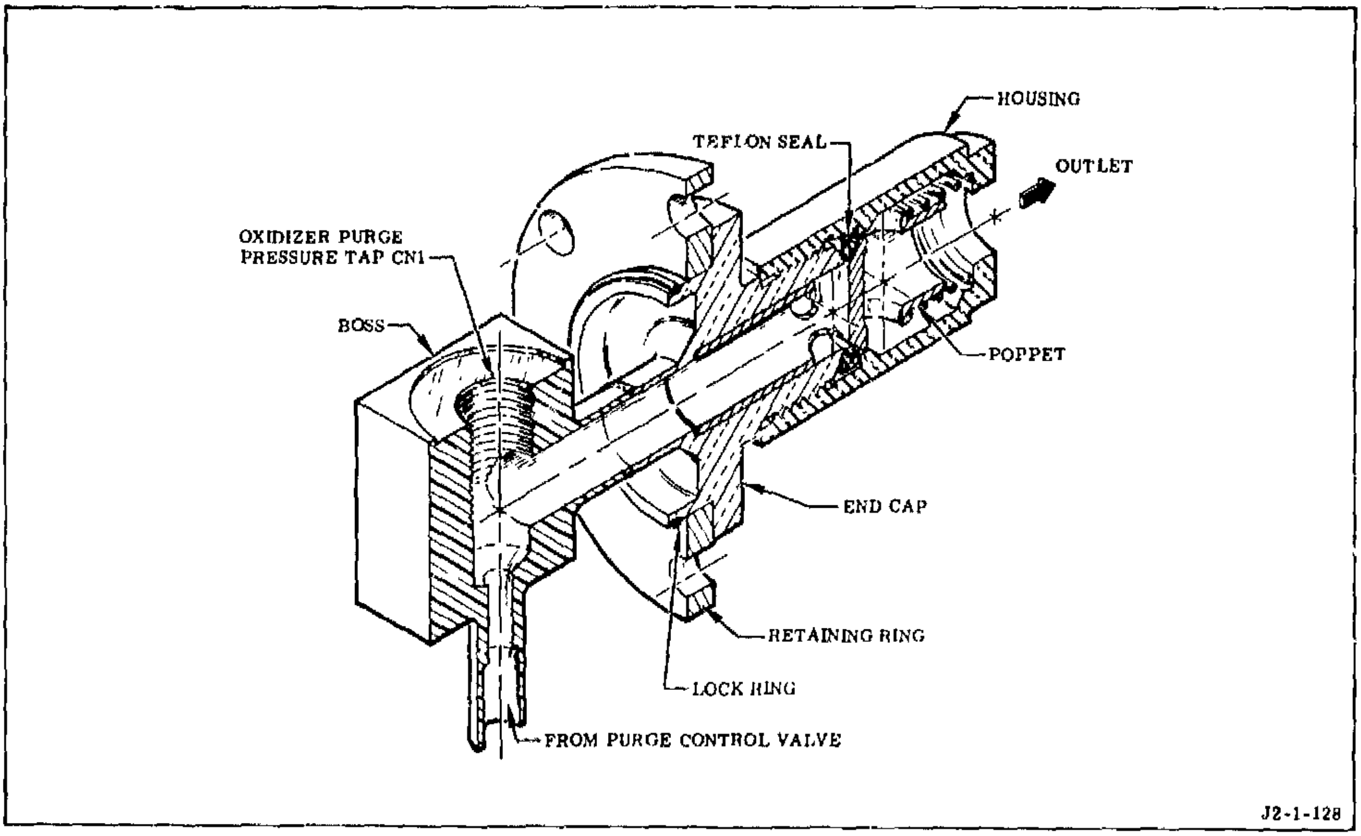


Figure 1-48. Oxidizer Injector Purge Check Valve

1-123. FLIGHT INSTRUMENTATION SYSTEM DESCRIPTION.

1-124. The flight instrumentation system monitors engine performance during checkout, test, and flight operations. The system consists of the primary flight instrumentation package, the auxiliary flight instrumentation package, pressure and temperature transducers, valve position indicators, oxidizer and fuel flowmeters, turbopump speed transducers, and associated electrical harnesses.

1-125. FLIGHT INSTRUMENTATION PACKAGES.

1-126. There are two flight instrumentation packages in the instrumentation system, the primary and the auxiliary. The primary flight instrumentation package (figure 1-49) includes parameters critical to all engine static firings and vehicle flights. A pneumatic line connects the pneumatic control package to the case of the primary instrumentation package, using the case as an accumulator for the pneumatic control system. The auxiliary flight instrumentation package (figure 1-50) contains noncritical and/or redundant measurements for obtaining additional parameters to help evaluate engine operation. Design of the auxiliary package allows for deletion or substitution of parameters as necessary. The packages are pressurized to prevent entry of moisture and contaminants. The pressure transducers on both packages have welded stub-out connections.

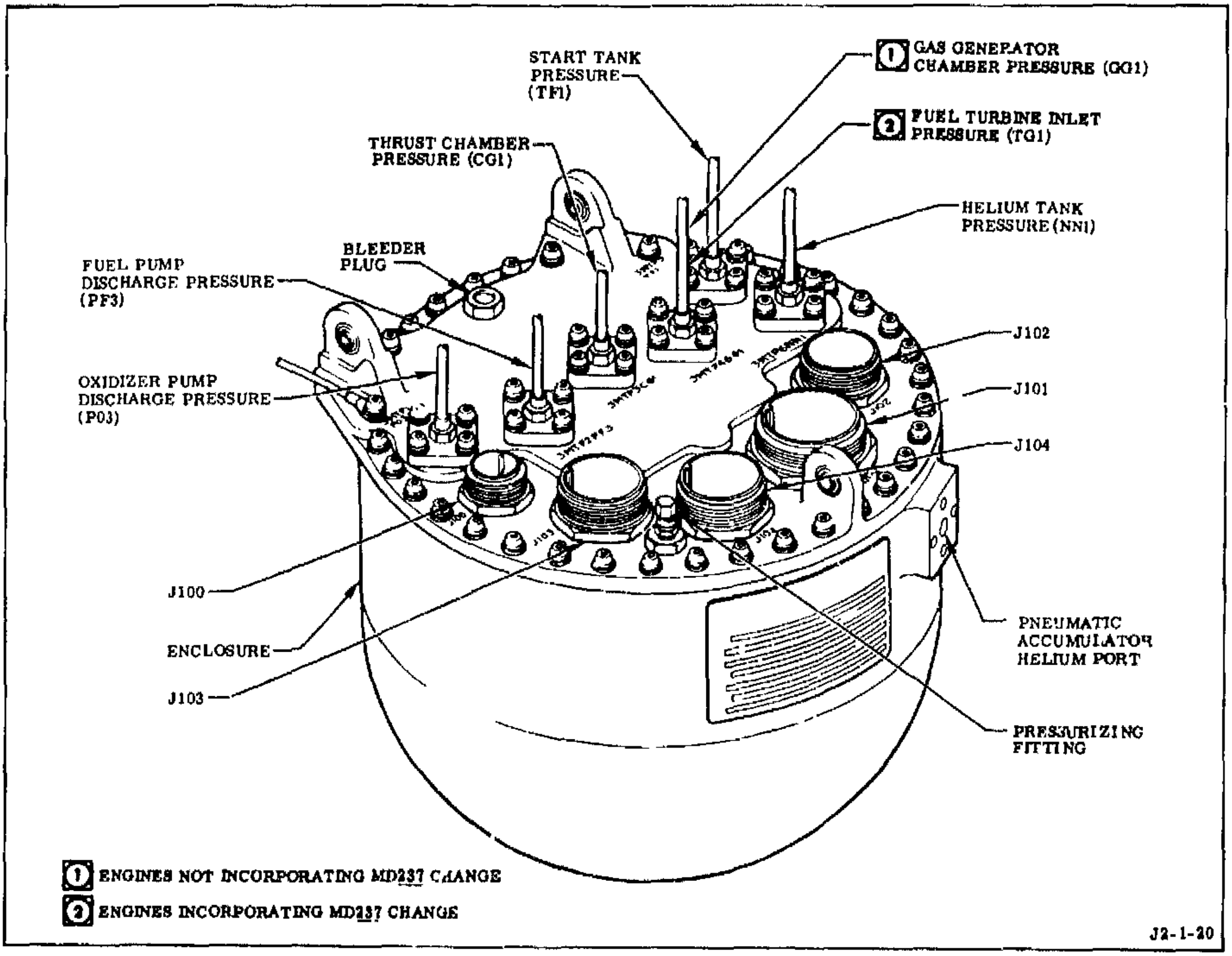


Figure 1-49. Primary Flight Instrumentation Package

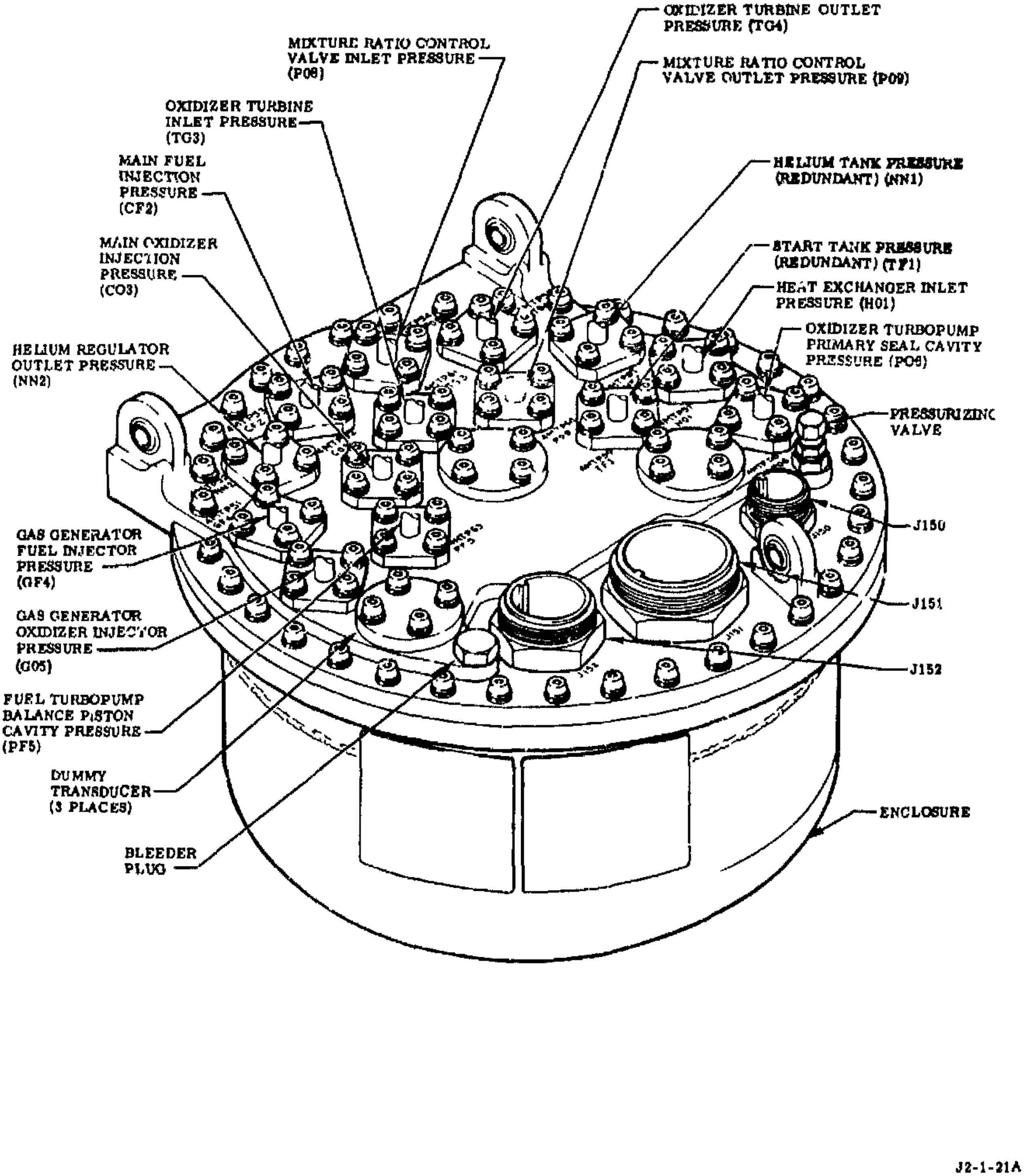


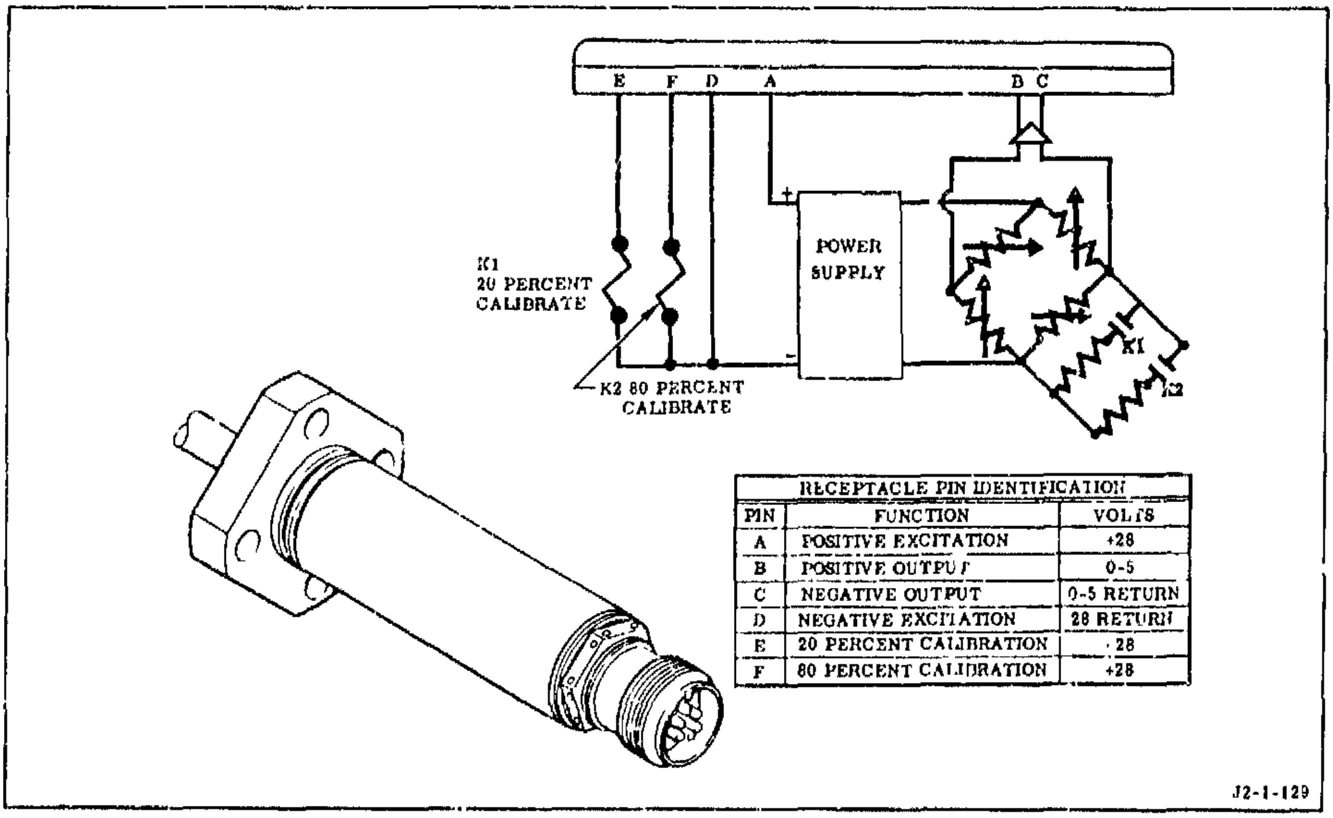
Figure 1-50. Auxiliary Flight Instrumentation Package

1-127. PRESSURE TRANSDUCERS.

1-128. The pressure transducers (figure 1-51) in the flight instrumentation system are dc input, dc output, absolute pressure transducers consisting of a mechanical-force-summing element coupled to an electrical bridge. The output of the electrical bridge is directly proportional to the pressure applied to the mechanical-force-summing network. All four of the bridge elements in the transducer are active. For each bridge element that increases impedance with increasing pressure, a second bridge element decreases impedance with increasing pressure. These elements are connected into the bridge in such a way as to obtain maximum sensitivity from the bridge. The transducer also has the necessary circuit elements to isolate the output from the input and to provide a regulated bridge excitation voltage, all necessary bridge amplification, bridge output demodulation if required, and to provide all required output filtration so that the transducer can be excited with a nominal 28-vdc input and a 5-vdc output at full pressure range. The transducer is capable of simulating the output at 20 and 80 percent of its operating range. The application of 28 vdc to pins E or F activates a switching circuit that substitutes a resistor in the bridge network, thereby simulating the bridge output for 20 or 80 percent of the operating range of the instrument.

1-129. TEMPERATURE TRANSDUCERS.

1-130. The temperature transducers (figure 1-52) in the flight instrumentation system are the platinum resistance type. The resistance bulbs have a three-wire termination that allows a bridge completion with a transmission line in opposite legs of the bridge, making zero and sensitivity changes negligible with variations in line length and resistance. Each transducer is supplied with its own resistance-versus-temperature calibration over a specified range. While all of the transducers operate on the same principle and the electrical connections are identical, the physical configurations of the various transducers differ with the installation and measurement requirements. During static testing, a chromel-alumel thermocouple is used as a sensor for the hot-gas overtemperature device, because the response of resistance transducers is not fast enough to provide adequate protection.



RECEPTACLE PIN IDENTIFICATION		
PIN	FUNCTION	VOLTS
A	POSITIVE EXCITATION	+28
B	POSITIVE OUTPUT	0-5
C	NEGATIVE OUTPUT	0-5 RETURN
D	NEGATIVE EXCITATION	28 RETURN
E	20 PERCENT CALIBRATION	+28
F	80 PERCENT CALIBRATION	+28

Figure 1-51. Pressure Transducer

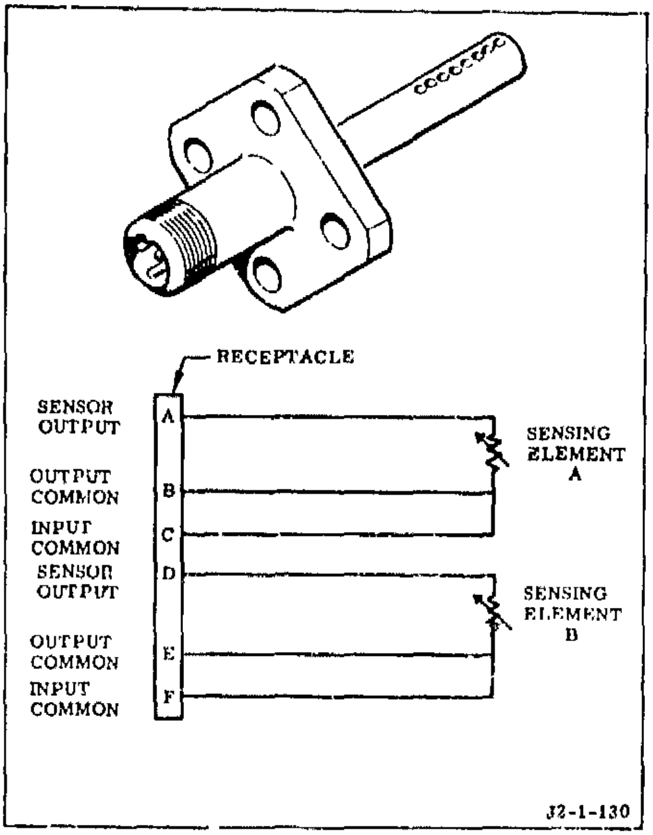


Figure 1-52. Temperature Transducer

1-131. OXIDIZER AND FUEL FLOWMETERS.

1-132. The oxidizer and fuel flowmeters (figure 1-53) are turbine-type, volumetric, liquid flowmeters, mounted in the propellant high-pressure ducts to measure the flow of propellants into the thrust chamber. Each flowmeter consists of a helical-vaned rotor assembly that senses the propellant flow, flow straighteners that direct the propellant flow across the rotor, and a magnetic pickup that produces an output that is suitable for direct telemetry. Each magnetic pickup contains an auxiliary isolated coil for checkout. Supplying a voltage to the checkout coil induces a signal in the measurement coil. During engine operation, the flow of propellant through the flowmeter sets the rotor in motion. The speed of the rotor is a function of the volumetric flowrate of the propellant and is detected by the magnetic pickup. The flux lines through the coil build up and collapse, generating an electromotive force (emf) that can be measured at the connector. The magnitude of this emf is a function of the speed of the rotor, the distance of the pickup from the top of the blades, and the blade material (a constant). The generated frequency depends on rotor speed and number of blades and is in direct correlation to flowrate. The fuel flowmeter has a four-vane rotor that produces four electrical impulses a revolution, and the oxidizer flowmeter has a six-vane rotor that produces six electrical impulses a revolution.

1-133. TURBOPUMP SPEED TRANSDUCERS.

1-134. The fuel and oxidizer turbopumps are equipped with magnetic pickups to measure turbopump speed for the instrumentation system and to provide a turbine overspeed cutoff signal for static testing. Turbopump shaft speed is sensed by the magnetic pickup that alternately disturbs a magnetic field with 12 equally spaced slots in the turbopump rotor assembly. As the turbopump shaft rotates and each slot passes the tip of the pickup, the flux density of the pickup coil is interrupted. The buildup and collapse of the flux lines generate a voltage across the leads. This voltage is proportional to the pump shaft speed. The output of the magnetic transducers is designed for generation of a 1-3 volt pulse suitable for direct telemetry. The fuel turbopump rotor is made from K-monel, which does not exhibit magnetic qualities until chilled to -300° F. Therefore, checkout of the tachometer by spinning the turbopump is not feasible at ambient temperatures. An electrical checkout can be made, however, by applying a voltage in the signal coil. This check may be made at either ambient or cryogenic temperatures.

1-135. VALVE POSITION INDICATORS.

1-136. The primary flight instrumentation provides a position indicator signal for the main oxidizer valve, the main fuel valve, the gas generator control valve, the oxidizer turbine bypass valve, the start tank discharge valve, the mixture ratio control valve, the augmented spark igniter valve, and propellant bleed valves. The position indicators on the components are 2,000-ohm potentiometers and/or position switches. Voltage ratio is used to determine potentiometric valve positions. Voltage ratio is obtained from the telemetry potentiometer signal and is calculated from the formula

$$\text{Voltage ratio} = \frac{\text{Potentiometer output in volts}}{\text{Potentiometer input in volts}}$$

The voltage drop between the power supply and the engine interface must be considered when determining potentiometer input.

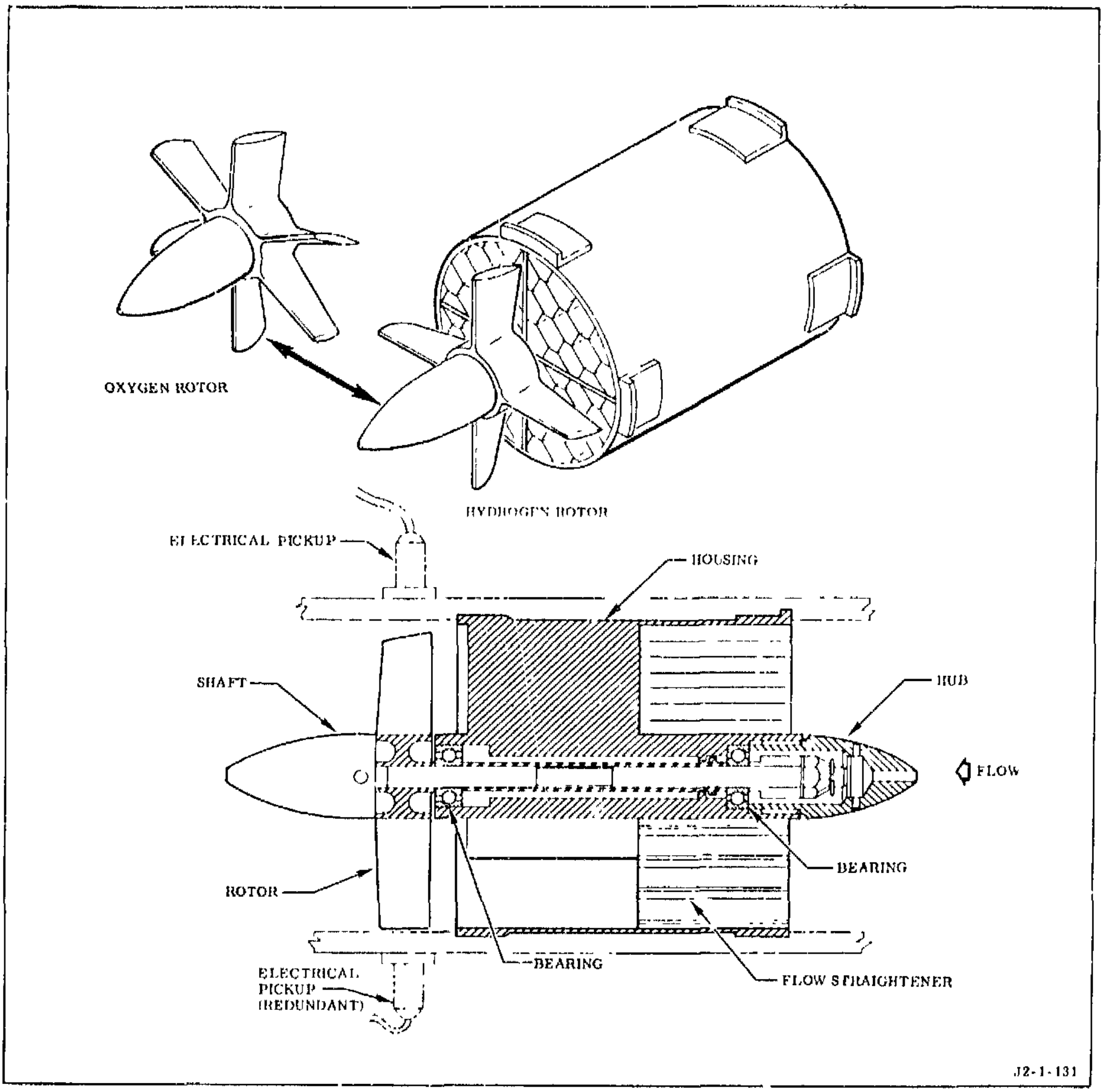


Figure 1-53. Oxidizer and Fuel Flowmeters

1-137. ENGINE INSULATION.

1-138. Various components of the J-2 engines are insulated to improve engine recirculation chilldown, eliminate formation of liquid air, maintain satisfactory start and restart temperature, and reduce normal heating during engine operation. As a result of the five-engine cluster used on the SII stage, insulation is installed to reduce overheating caused by backflow. The insulation materials and installation methods vary greatly from one component to another. This variation depends on the shape and location of the component, physical access, and the function and movement of the component.

1-139. The fuel turbopump volute, high-pressure fuel duct, fuel bleed line, and start tank are insulated on all engines to help maintain the cold temperature conditions that are required in the fuel system. A portion of the fuel bleed line and bracket are insulated to eliminate the formation of liquid air.

1-140. On SII stage engines, insulation is installed on the thrust chamber hat bands and reinforcing rings aft of the stage heat shield to provide thermal protection of these areas from base-heating during engine operation. Forward of the heat shield, the main fuel valve, electrical control assembly, and the electrical control assembly strut are also insulated to provide thermal protection against potential heat damage. The fast-shutdown valve and the oxidizer turbine bypass valve are insulated to prevent overheating caused by boattail recirculation of hot gases if an engine shuts down in flight. The oxidizer turbopump volute, main oxidizer valve, oxidizer inlet duct, oxidizer high-pressure duct, mixture ratio control valve, oxidizer bleed line, and the oxidizer tank pressurization line are insulated to improve oxidizer system chilldown characteristics during stage loading and recirculation operations.

1-141. On SIVB stage engines, the thrust chamber tubes, below the fuel inlet manifold, are insulated to maintain the thrust chamber as cold as possible after chilldown, until the stage reaches the first firing sequence. After launch, the insulation minimizes the effect of solar heat on the thrust chamber between engine starts.

1-142. ENGINE OPERATION.

1-143. Engine operation is separated into three phases: start sequence, mainstage, and cutoff. The operation presented is typical for a single engine run. Engine operation is illustrated by an engine logic diagram (figure 1-54), engine start and cutoff sequence flow charts (figures 1-55 and 1-56), engine schematics reflecting engine conditions during each stage of operation (figures 1-57, 1-58, and 1-59), and a block diagram flow chart (figure 1-60) showing all phases of engine operation.

1-144. START SEQUENCE.

1-145. When engine start is initiated, the spark exciters in the electrical control assembly are energized and provide energy for the augmented spark igniter and the gas generator spark igniters. The helium control and ignition-phase control valves are simultaneously energized, allowing helium from the helium tank to flow through the helium (pneumatic) regulator to the pneumatic control system. The helium is routed through the internal accumulator check valve in the pneumatic control package so that there is continued pressure to the engine valves if the helium supply fails. Regulated helium flows from the port on the pneumatic control package to fill the pneumatic accumulator, to close the propellant bleed valves, and to purge the thrust chamber oxidizer injector and gas generator oxidizer injector manifold through the purge control valve. A continuous purge to the oxidizer turbopump intermediate seal cavity flows from a port located between the regulator and internal check valve in the pneumatic control package. Helium flows through the normally open port of the mainstage control valve to the closing control port of the main oxidizer valve and to the opening control port of the purge control valve, which allows the thrust chamber oxidizer injector and gas generator oxidizer injector purges to flow. The normally open port of the mainstage control valve also supplies opening control pressure to the oxidizer turbine bypass valve. The ignition-phase control valve, when actuated, routes helium to open the augmented spark igniter valve and the main fuel valve and supplies pressure to the inlet port of the sequence valve, located within the main oxidizer valve first-stage actuator. Both propellants are now flowing under tank pressure through the stationary turbopumps.

1-146. The augmented spark igniter valve opens and oxidizer enters the augmented spark igniter chamber. As the main fuel valve opens, hydrogen enters the augmented spark igniter chamber and the thrust chamber down tubes, then continues up the tubes. The sequence valve, located within the main fuel valve assembly, is opened when the fuel valve reaches approximately 90-percent open and routes helium to the pneumatic supply port of the start tank discharge valve control valve. Simultaneously with engine start, the start tank discharge valve delay timer in the sequence controller is energized. Upon expiration of the timer (provided the stage-supplied mainstage enable signal is present), the start tank discharge valve control valve and the ignition-phase timer in the sequence controller are energized. If the mainstage enable signal has not been supplied at the expiration of the start tank discharge valve delay timer, energization of the start tank discharge valve control valve and the ignition-phase timer will not occur. Thrust chamber prechill fuel lead times are controlled by the stage-supplied mainstage enable signal. As the start tank discharge valve control valve energizes and the discharge valve opens, gaseous hydrogen, stored under pressure in the start tank, flows through the turbine drive system, accelerating both turbopumps to the proper operating levels to allow subsequent ignition and power buildup of the gas generator. The relationship of fuel turbopump to oxidizer turbopump speed buildup is controlled by the normally open oxidizer turbine bypass valve that permits some of the gas to bypass the oxidizer turbine.

1-147. On engines not incorporating MD338 change, augmented spark igniter combustion must be detected by the fusible-link ignition detector probe installed in the augmented spark igniter. On engines incorporating MD338 change, the fusible-link probe is disconnected and electrically bypassed by a dummy probe, which results in a continuous ignition-complete signal being present in the control circuitry whenever engine electrical power is turned on. Absence of ignition detection signal will cause cutoff at the expiration of the ignition-phase timer. If the ignition-complete signal is present at expiration of the ignition-phase timer, the mainstage control valve is energized. Simultaneously, the sparks deenergized timer is energized and the start tank discharge valve control valve is deenergized, causing the start tank discharge valve to close. Helium pressure is vented from the main oxidizer valve closing control port and from the opening control port of the purge control valve through the normally open port of the mainstage control valve. The purge control valve closes, terminating the thrust chamber oxidizer injector and gas generator oxidizer injector manifold purges. Opening control pressure from the normally closed port of the mainstage control valve is routed to the first- and second-stage opening control ports of the main oxidizer valve. Applying opening control pressure in this manner and controlled venting of the main oxidizer valve closing pressure provides a controlled ramp opening of the main oxidizer valve. The main oxidizer valve closing control pressure is vented through a thermal-compensating orifice to provide a constant valve ramp through all temperature ranges. The sequence valve, located within the main oxidizer valve assembly, supplies pneumatic pressure to the opening control port of the gas generator control valve and through an orifice to the closing control port of the oxidizer turbine bypass valve.

1-148. The propellants flowing into the gas generator are ignited by spark plugs; hot-gas products of combustion pass through the exhaust duct to drive the turbines; high-pressure duct propellant flows increase; and the propellants, now flowing under pump pressure, are ignited in the thrust chamber.

1-149. MAINSTAGE OPERATION.

1-150. Transition into mainstage occurs as the turbopumps accelerate to steady-state speeds. As oxidizer injection pressure increases toward the steady-state level, a mainstage OK signal is generated by either one of the mainstage OK pressure switches. (Cutoff occurs if no signal is generated before expiration of the sparks deenergized timer.) The augmented spark igniter and gas generator spark exciters are deenergized by expiration of the sparks deenergized timer. Cutoff will occur if both pressure-switch-activated signals (mainstage OK) are lost during mainstage operation.

1-151. Steady-state operation is maintained until a cutoff signal is initiated. During this period, gaseous hydrogen is tapped from the forward fuel (injection) manifold to pressurize the vehicle fuel tank. The SII stage oxidizer tank is pressurized by gaseous oxygen, formed by routing liquid oxygen from the oxidizer high-pressure duct through the heat exchanger located in the oxidizer turbine exhaust duct. On SIVB stage engines, stage-supplied helium (instead of oxygen) is routed through the heat exchanger for oxidizer tank pressurization. On restart mission engines, gaseous hydrogen is bled from the thrust chamber forward fuel manifold and liquid hydrogen is bled from the augmented spark igniter fuel line, to refill the start tank for engine restart. Approximately 60 seconds of mainstage engine operation are required to refill the start tank. Engine mixture ratio control is provided by the mixture ratio control valve, which bypasses oxidizer from the oxidizer turbopump outlet back to the inlet. At a preselected time during engine operation, a command signal is supplied by the stage, to drive the mixture ratio control valve to one of its two discrete mixture ratio positions.

1-152. CUTOFF SEQUENCE.

1-153. The cutoff signal is received by the sequence controller, which simultaneously deenergizes the mainstage control and ignition-phase control valves and energizes the helium control deenergize timer. Opening control pressure is vented from the first- and second-stage main oxidizer valve opening actuators through the normally closed port of the mainstage control valve, while opening control pressure from the augmented spark igniter valve and the main fuel valve is vented through the normally closed port of the ignition-phase control valve.

1-154. Pneumatic control system pressure is routed from the normally open port of the mainstage control valve to the closing actuator of the main oxidizer valve and to the opening control port of the purge control valve. The purge control valve opens, allowing helium to flow to the check valve in the oxidizer injector purge line and to the check valve in the gas generator oxidizer purge line. These purges will flow when thrust chamber and gas generator chamber pressures decay below the level of control system pressure. The normally open port of the ignition-phase control valve routes helium to the closing control port of the augmented spark igniter valve and the main fuel valve and to the opening control port of the fast-shutdown valve which actuates, allowing the gas generator control valve opening control pressure to vent rapidly. All valves, except the oxidizer turbine bypass valve, are spring-loaded to the closed position and start to close as soon as opening pressure is vented. Fuel pressure in the gas generator control valve helps the spring close the valve. The oxidizer turbine bypass valve closing control pressure also vents through an orifice and the fast-shutdown valve. The oxidizer turbine bypass valve is spring-loaded to the normally open position and starts to open as closing pressure is vented. The normally open port of the mainstage control valve also supplies opening control pressure to the oxidizer turbine bypass valve to help the spring open the valve.

1-155. Expiration of the helium control deenergize timer causes the helium control valve to deenergize, which closes the valve and vents control system pressure through the oxidizer injector and gas generator oxidizer purges. As the control system pressure is vented to the actuation pressure of the normally closed purge control valve, the valve actuates closed and the purges stop. Pressure is now locked up between the check valve in the pneumatic control package and the normally open side of the mainstage and ignition phase control valves, the propellant bleed valve control ports, and the pneumatic accumulator, holding the bleed valves closed. This locked up pressure is bled off through an accumulator bleed orifice and vent port check valve, located in the line between the closing control actuator of the main fuel valve and the normally open port of the ignition phase control valve. As this pressure decays, the propellant bleed valves open by spring pressure and the cutoff sequence is complete.

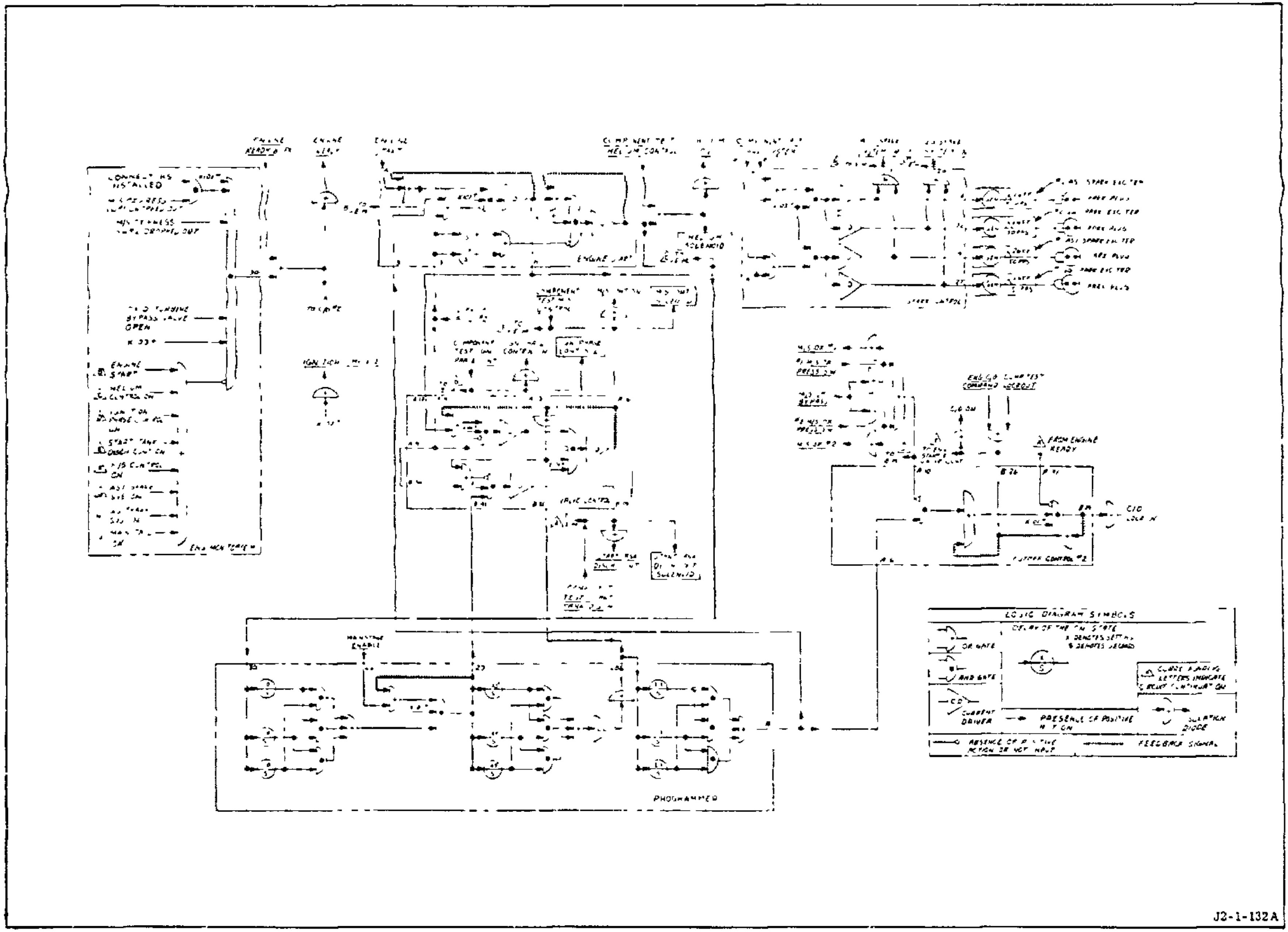
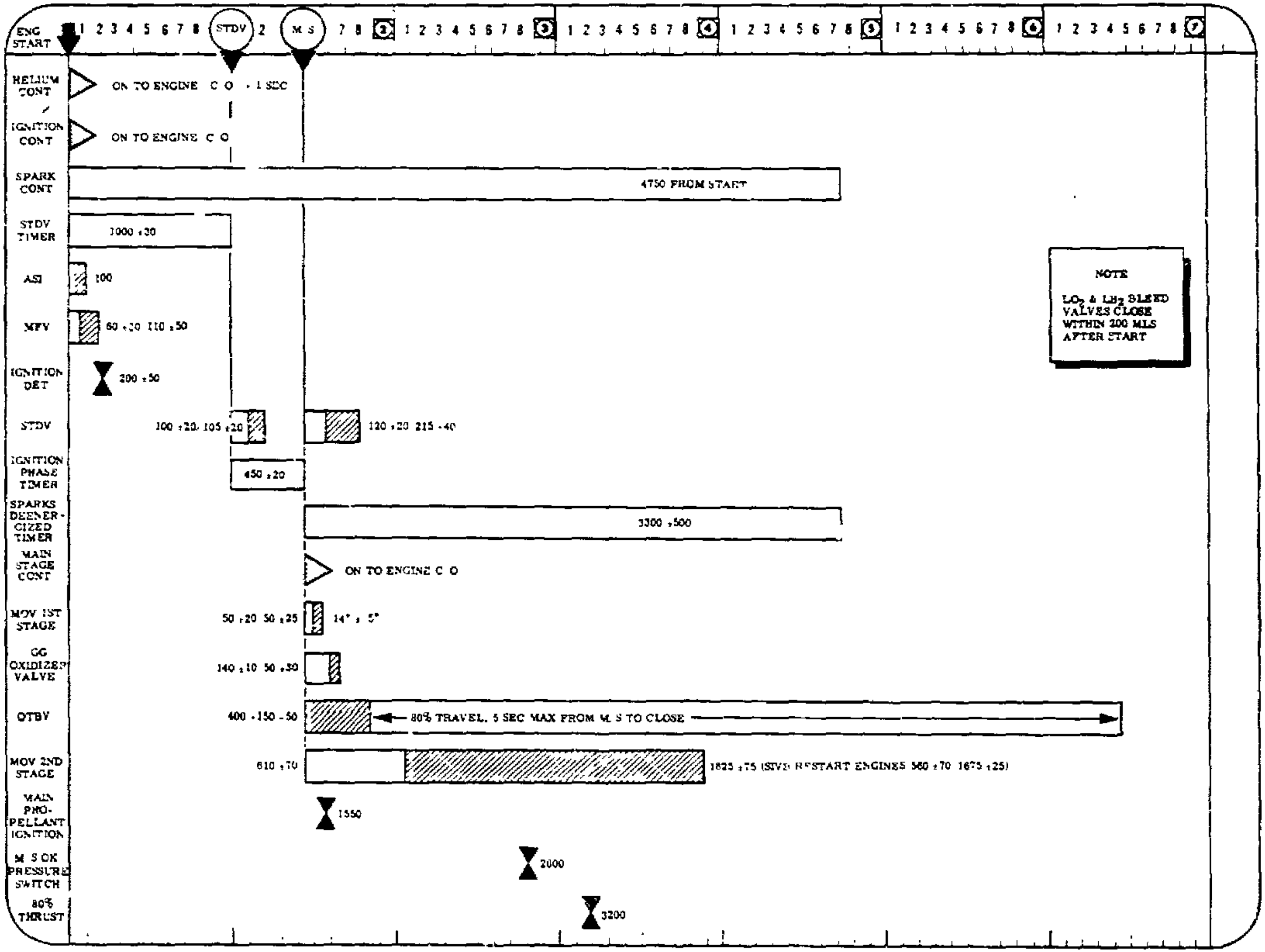


Figure 1-54. Engine Logic



J2-1-55A

Figure 1-55. Start Sequence

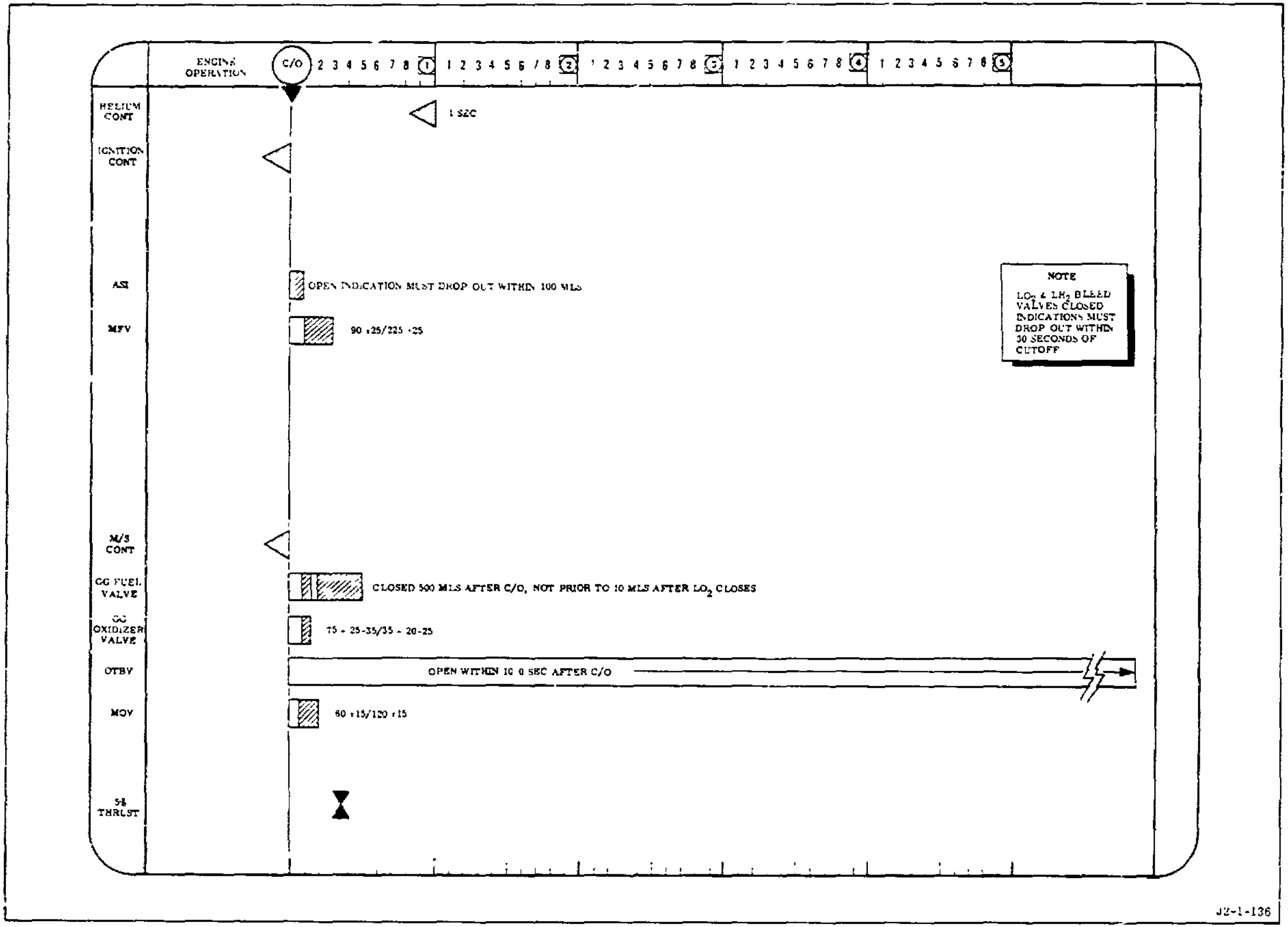


Figure 1-56. Cutoff Sequence

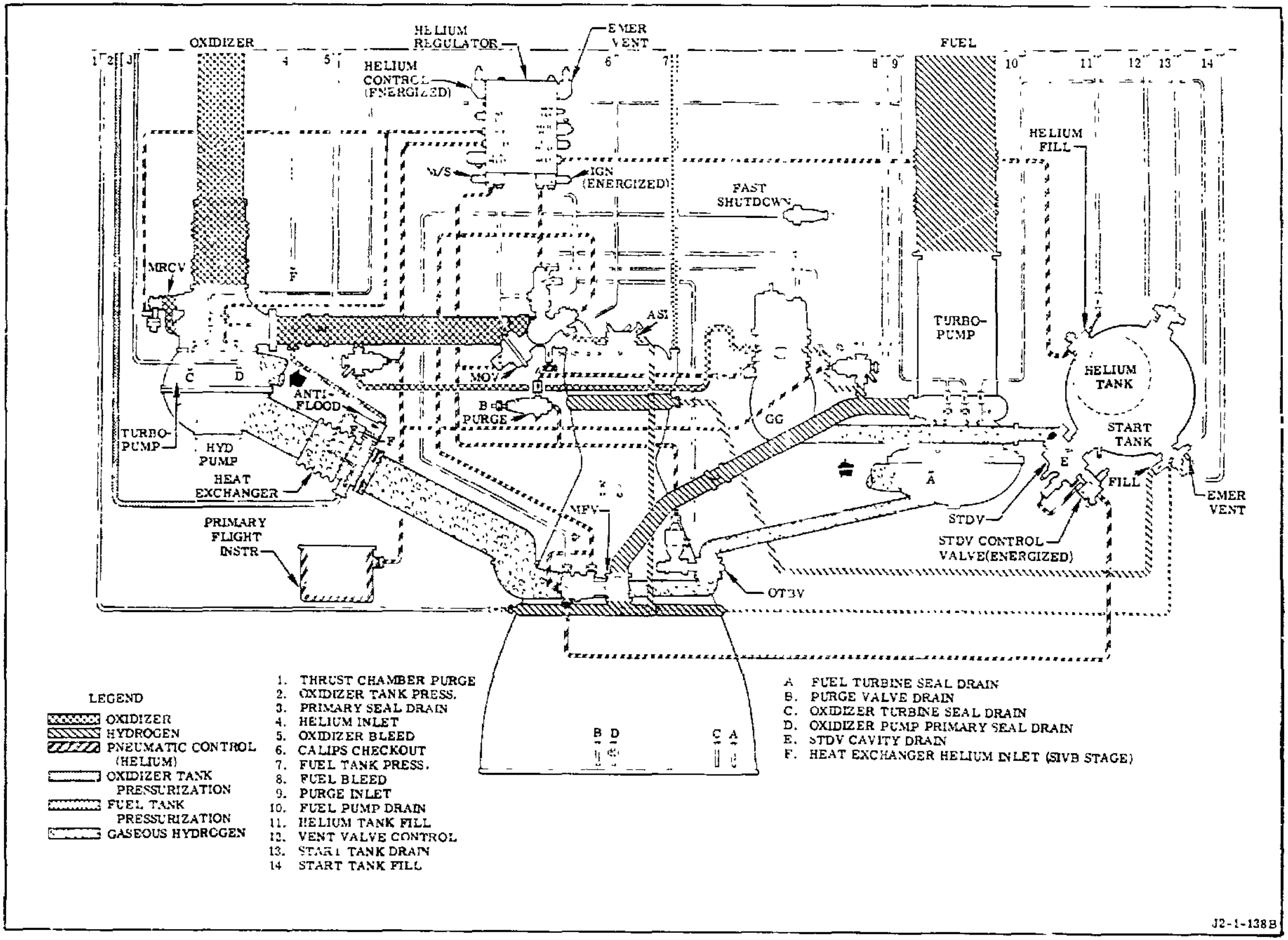


Figure 1-57. Ignition Phase Schematic

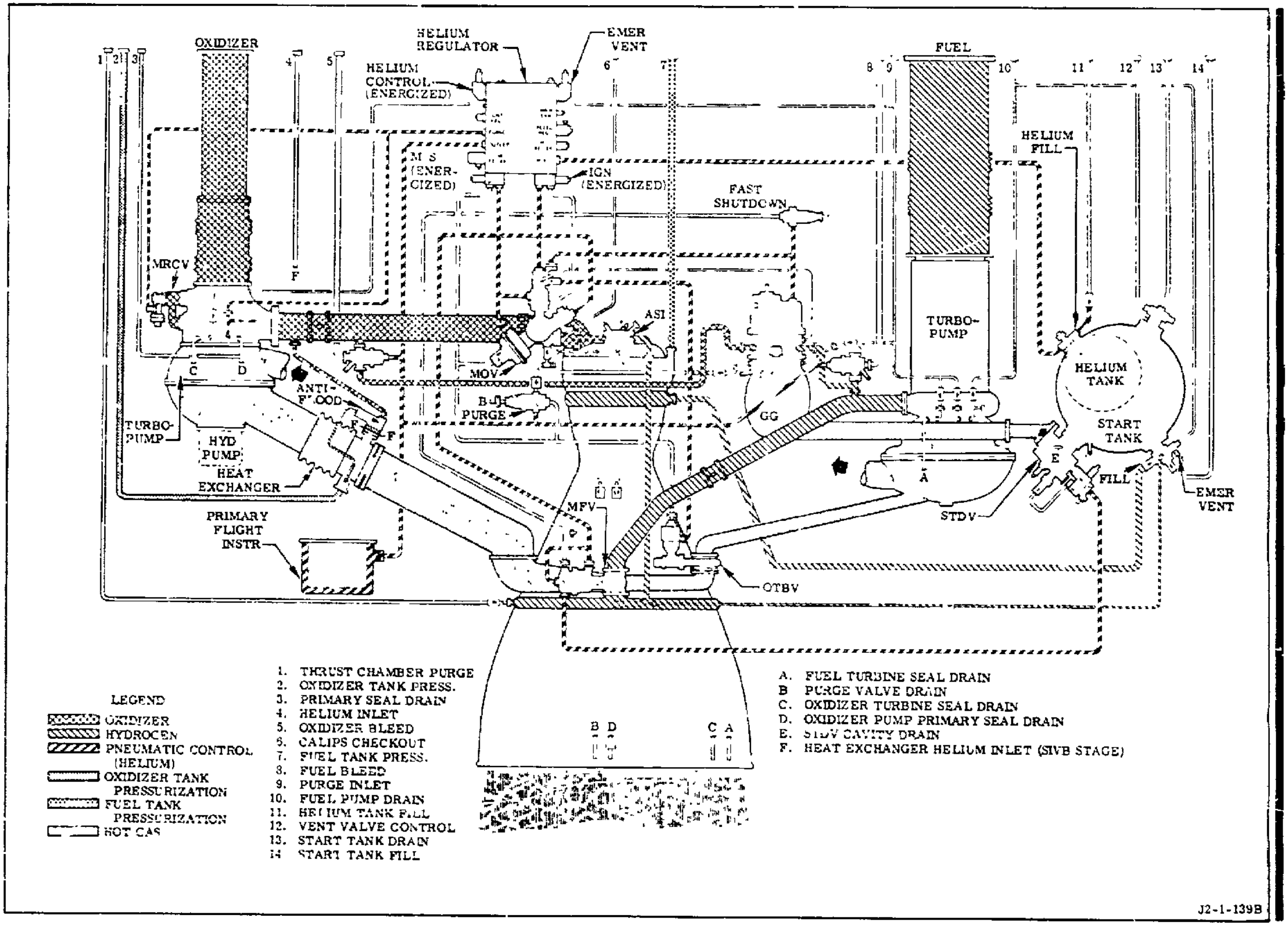


Figure 1-58. Mainstage Phase Schematic

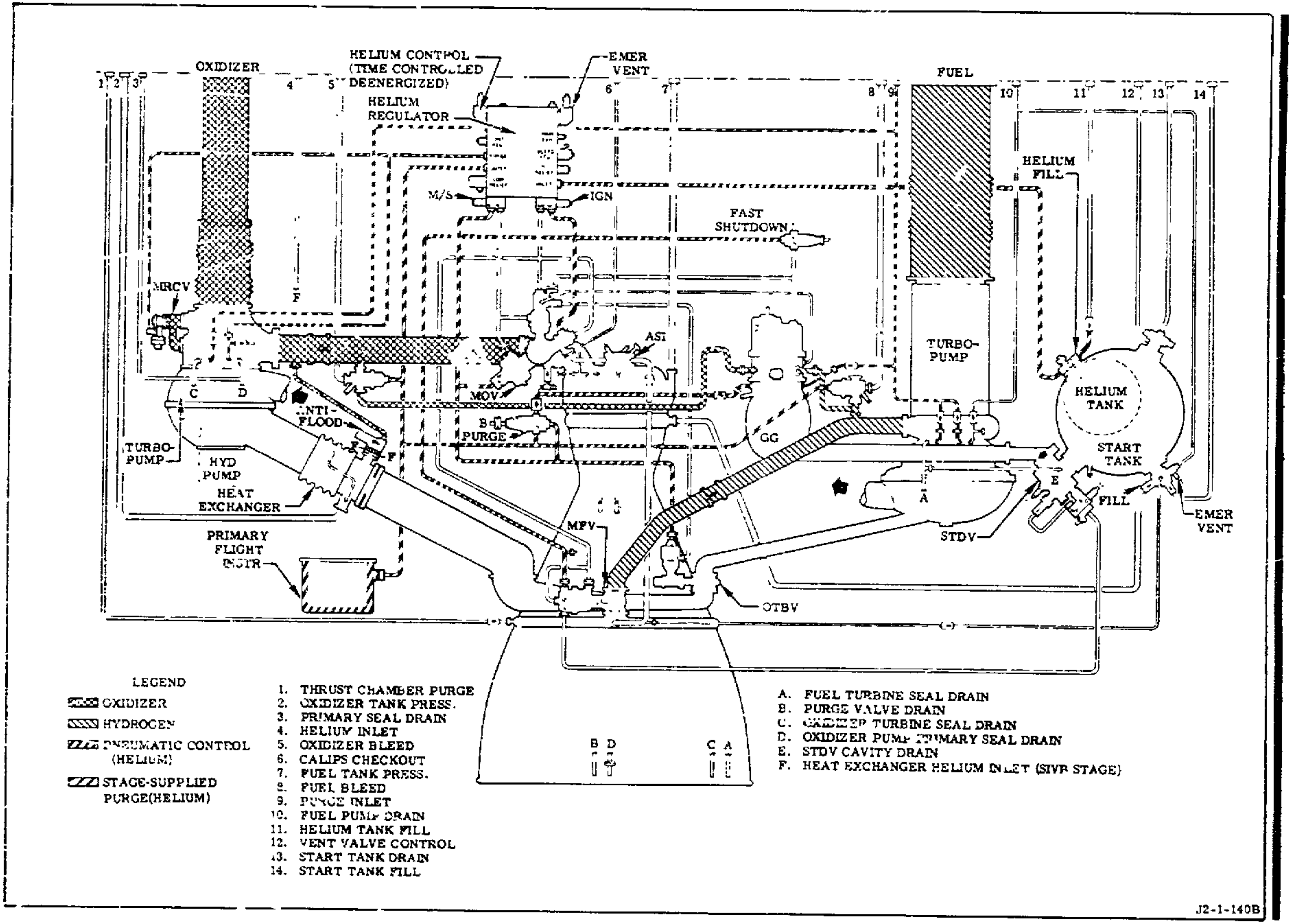


Figure 1-59. Cutoff Phase Schematic

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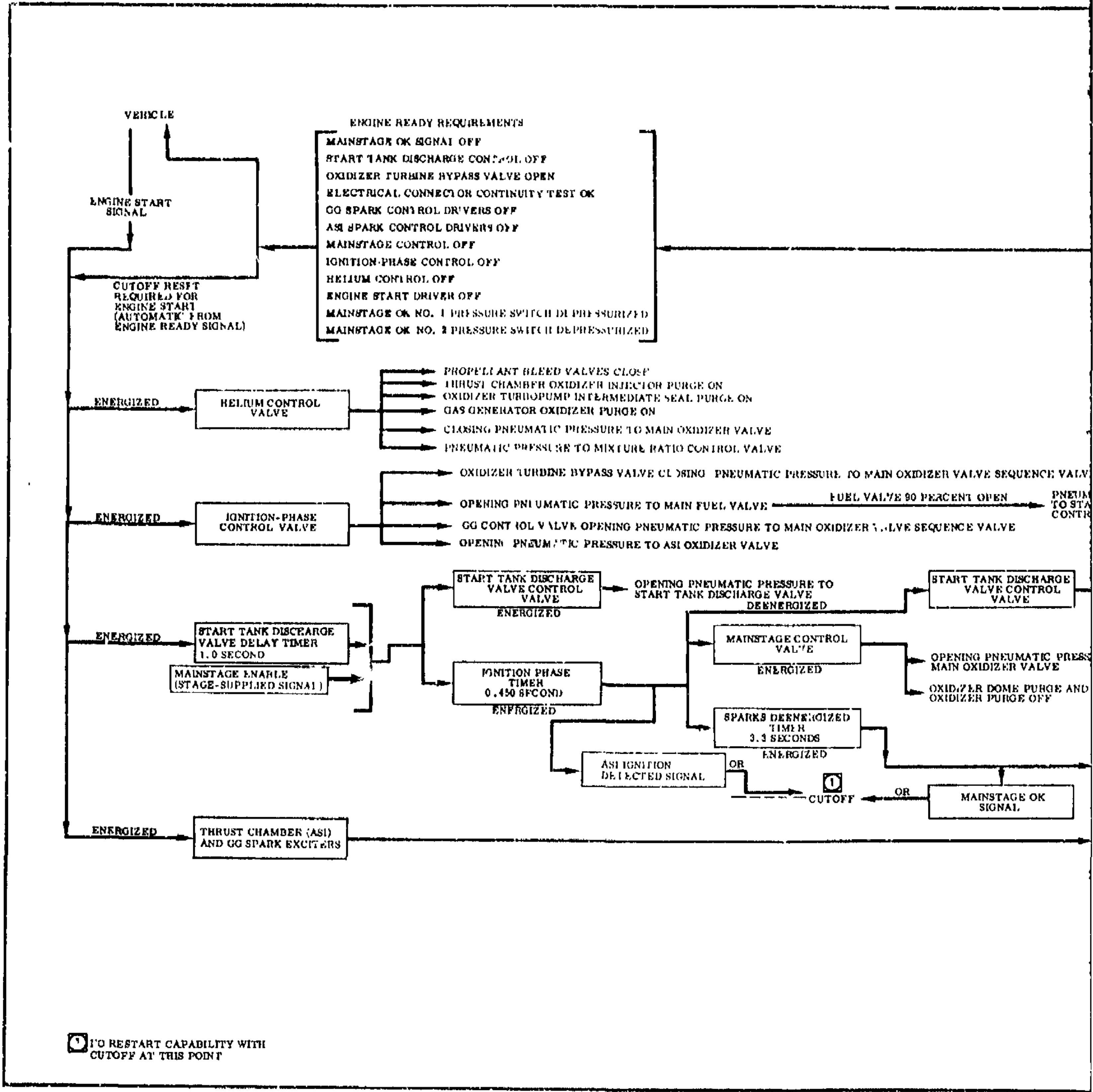
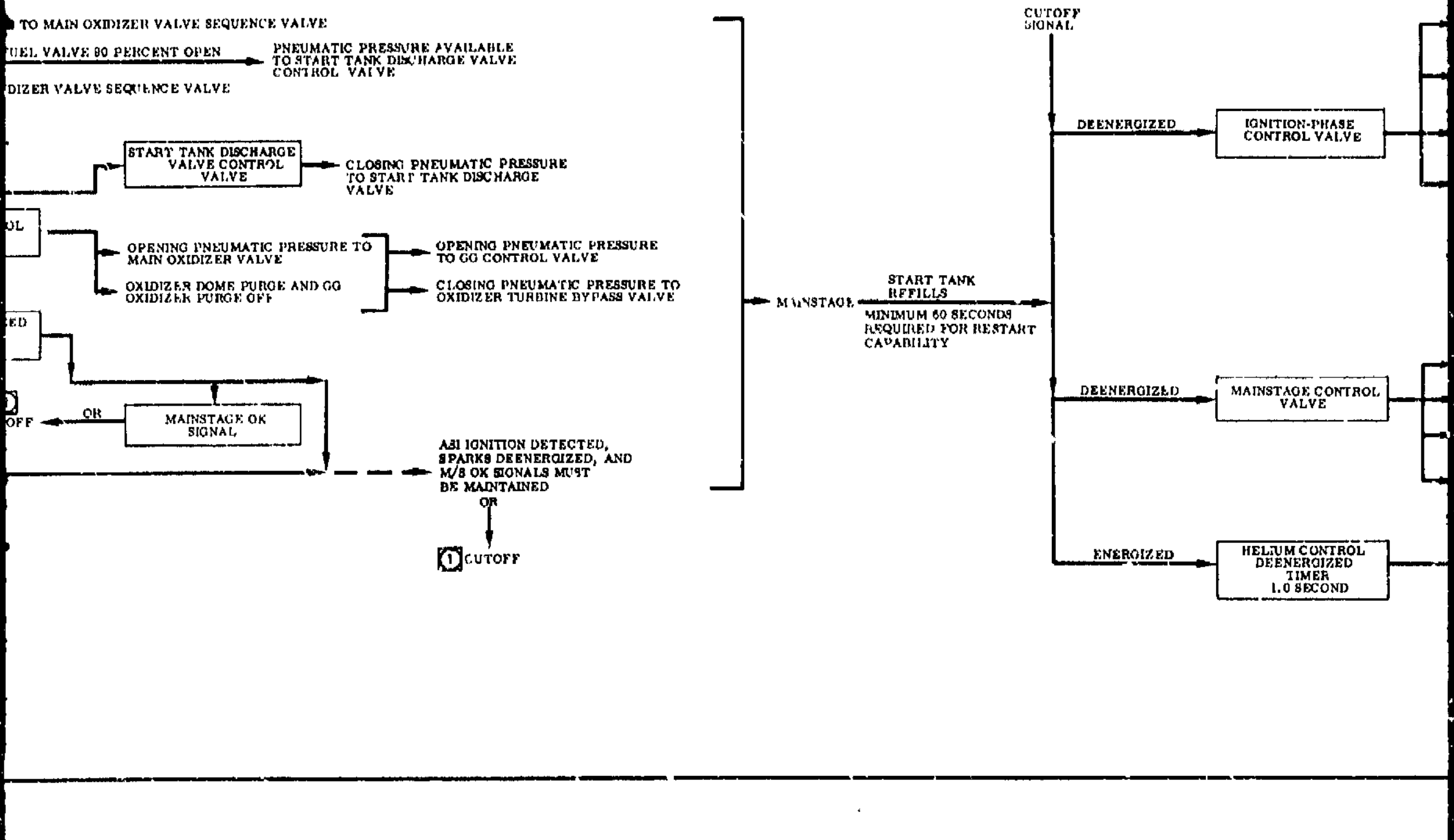
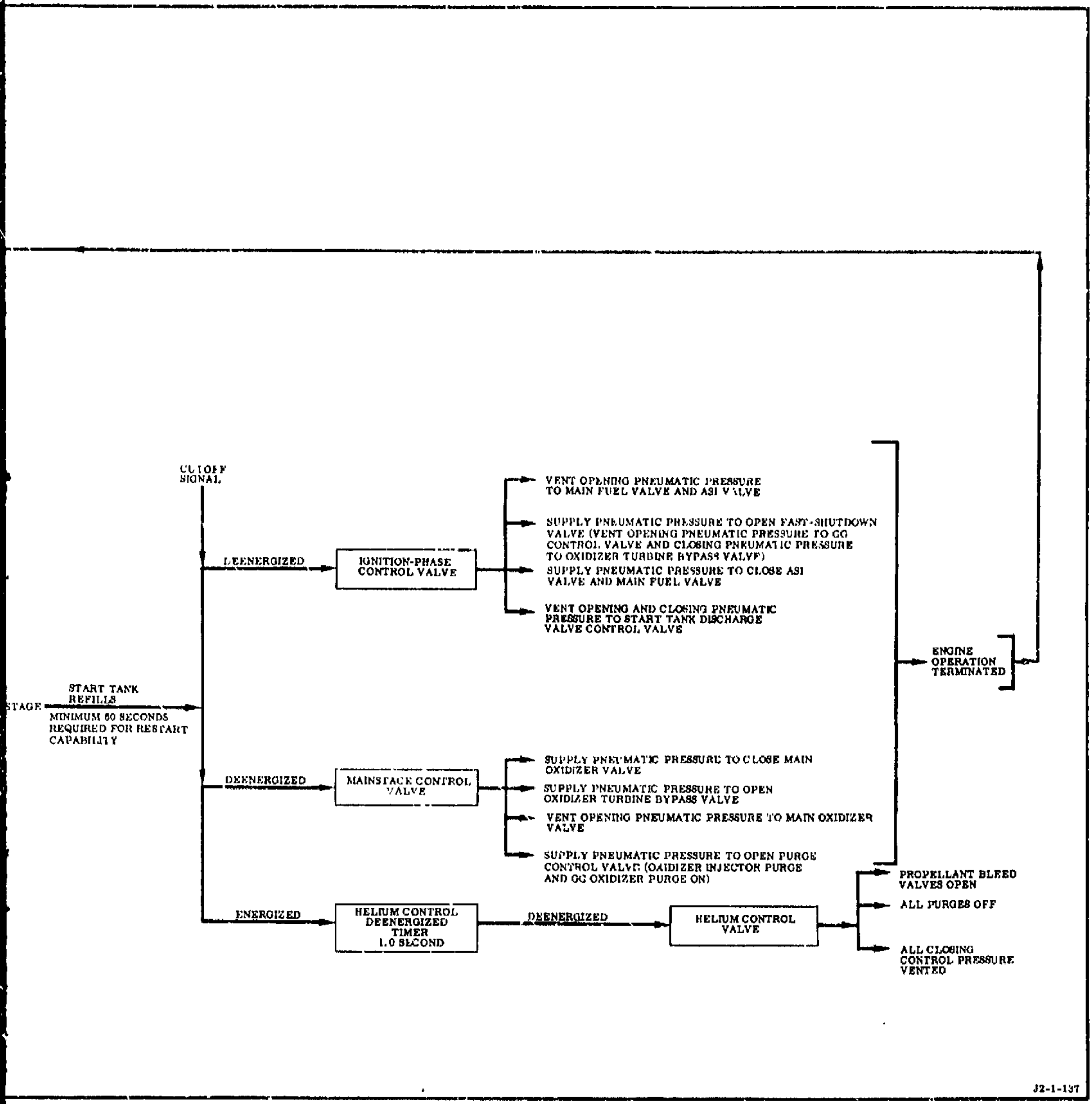


Figure 1-60. Start, Cutoff, and Restart Flow Diagram


TO MAIN OXIDIZER VALVE SEQUENCE VALVE
UEL VALVE 90 PERCENT OPEN
PNEUMATIC PRESSURE AVAILABLE TO START TANK DISCHARGE VALVE CONTROL VALVE
DIZER VALVE SEQUENCE VALVE
START TANK DISCHARGE VALVE CONTROL VALVE
CLOSING PNEUMATIC PRESSURE TO START TANK DISCHARGE VALVE
OL
OPENING PNEUMATIC PRESSURE TO MAIN OXIDIZER VALVE
OXIDIZER DOME PURGE AND GG OXIDIZER PURGE OFF
OPENING PNEUMATIC PRESSURE TO GG CONTROL VALVE
CLOSING PNEUMATIC PRESSURE TO OXIDIZER TURBINE BYPASS VALVE
ED
OFF
OR
MAINSTAGE OK SIGNAL
ASI IGNITION DETECTED, SPARKS DEENERGIZED, AND M/S OK SIGNALS MUST BE MAINTAINED
OR
1 CUTOFF
MAINSTAGE
START TANK REFILLS
MINIMUM 60 SECONDS REQUIRED FOR RESTART CAPABILITY
CUTOFF SIGNAL
DEENERGIZED
IGNITION-PHASE CONTROL VALVE
DEENERGIZED
MAINSTAGE CONTROL VALVE
ENERGIZED
HELIUM CONTROL DEENERGIZED TIMER 1.0 SECOND


CUTOFF SIGNAL
DEENERGIZED
IGNITION-PHASE CONTROL VALVE
VENT OPENING PNEUMATIC PRESSURE TO MAIN FUEL VALVE AND ASI VALVE
SUPPLY PNEUMATIC PRESSURE TO OPEN FAST-SHUTDOWN VALVE (VENT OPENING PNEUMATIC PRESSURE TO GG CONTROL VALVE AND CLOSING PNEUMATIC PRESSURE TO OXIDIZER TURBINE BYPASS VALVE)
SUPPLY PNEUMATIC PRESSURE TO CLOSE ASI VALVE AND MAIN FUEL VALVE
VENT OPENING AND CLOSING PNEUMATIC PRESSURE TO START TANK DISCHARGE VALVE CONTROL VALVE
ENGINE OPERATION TERMINATED
STAGE
START TANK REFILLS
MINIMUM 60 SECONDS REQUIRED FOR RESTART CAPABILITY
DEENERGIZED
MAINSTAGE CONTROL VALVE
SUPPLY PNEUMATIC PRESSURE TO CLOSE MAIN OXIDIZER VALVE
SUPPLY PNEUMATIC PRESSURE TO OPEN OXIDIZER TURBINE BYPASS VALVE
VENT OPENING PNEUMATIC PRESSURE TO MAIN OXIDIZER VALVE
SUPPLY PNEUMATIC PRESSURE TO OPEN PURGE CONTROL VALVE (OXIDIZER INJECTOR PURGE AND GG OXIDIZER PURGE ON)
ENERGIZED
HELIUM CONTROL DEENERGIZED TIMER 1.0 SECOND
DEENERGIZED
HELIUM CONTROL VALVE
PROPELLANT BLEED VALVES OPEN
ALL PURGES OFF
ALL CLOSING CONTROL PRESSURE VENTED
J2-1-137

SECTION II

THRUST CHAMBER AND GIMBAL SYSTEM

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Pages 2-1 through 2-8 deleted.

SECTION III

GAS GENERATOR AND EXHAUST SYSTEM

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SECTION IV

PROPELLANT FEED SYSTEM

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SECTION V

CONTROL SYSTEM

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Pages 5-1 through 5-14 deleted.

SECTION VI

START SYSTEM

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Pages 6-1 through 6-10 deleted.

SECTION VII

INSTRUMENTATION SYSTEM

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Pages 7-1 through 7-38 deleted.

SECTION VIII

PERFORMANCE

TABLE OF CONTENTS

PARAGRAPH PAGE

8-1. SCOPE. This section contains data pertinent to engine system performance and is presented as an aid in analyzing and determining certain specific conditions. The data represents the latest available information. Changes may be made as additional test data becomes available.

8-2. AVERAGE ENGINE PERFORMANCE VALUES.

8-3. Average engine performance values and standard deviations are presented in figures 8-1 and 8-2. These values are determined at standard altitude conditions and rated conditions of engine thrust, engine mixture ratio, and turbine inlet temperature. The average values were obtained by performing an engine-cycle balance, using average values of hardware characteristics. Only engine runs with constant hardware and orificing were considered. The engine-to-engine and run-to-run variations were calculated directly from the results of each test. Average engine performance values for 230K engines are also shown on a schematic (figure 8-3). These values were obtained during mainstage condition at maximum propellant utilization (60-second data slice). The engine balance data is based upon a power extraction of 15 horsepower at the accessory drive pad. The accessory drive pad is described in section IX.

8-4. Engine configuration changes at certain points in the production schedule result in some variations in performance.

8-5. Notable changes responsible for performance variations are as follows:

a. At engine J-2025, the nominal calibration point changed to 225,000 pounds thrust, 5.50 engine mixture ratio, and 1,200° F fuel turbine inlet temperature.

b. At engine J-2060, the nominal calibration point changed to 230,000 pounds thrust, 5.50 engine mixture ratio, and 1,200° F fuel turbine inlet temperature.

8-6. Gaseous oxygen for vehicle oxidizer tank pressurization is bled from the oxidizer turbopump discharge duct through a heat exchanger in the hot-gas duct. The vehicle fuel tank is pressurized with gaseous hydrogen from a tap at the thrust chamber fuel injection manifold. The effects of tank pressurization flowrate changes versus engine balance are described in this section. Engine specific impulse and mixture ratio do not include the propellants diverted for tank pressurization. On engines incorporating MD105 or MD194 change, the tap on the oxidizer turbopump discharge duct for oxidizer tank pressurization is capped and a separate customer connect line is provided for supplying stage helium to the heat exchanger for oxidizer tank pressurization.

8-7. ENGINE PERFORMANCE AT VARIOUS ALTITUDES.

8-8. The J-2 rocket engine is designed for upper-stage vehicle application. It has a relatively large nozzle expansion area ratio of 27.15:1. At sea level, the exhaust nozzle is capable of being equipped to operate with no jet separation over the nominal range of engine operation.

Parameter	Unit of Measurement	Mean[a]	Standard Deviations (Percent)	
			Engine-to-Engine	Run-to-Run
PROPELLANTS				
Oxidizer density	lb/cu ft	70.79	--	--
Fuel density	lb/cu ft	4.40	--	--
Fuel temperature	°R	37.156	--	--
	°F	-422.844	--	--
Oxidizer temperature	°R	164.476	--	--
	°F	-295.524		
ENGINE				
Thrust (altitude)	lb	225,000[b]	--	--
Thrust (sea level)	lb	156,400	--	--
Specific impulse (altitude)	sec	423.8	0.18	0.16
Specific impulse (sea level)	sec	293.81	--	--
Mixture ratio	O/F	5.50[b]	--	--
Rated duration	sec	500.00	--	--
Oxidizer weight flowrate (thrust chamber plus gas generator)	lb/sec	449.3	0.18	0.16
Fuel weight flowrate (thrust chamber plus gas generator)	lb/sec	81.68	0.18	0.16
Chamber pressure (injector end)	psia	762.6[c]	0.85	0.21
Chamber pressure (nozzle stagnation)	psia	702.2	0.85	0.21
Area expansion ratio		27.12:1	0.23	--

(a) Values include correction for runs made with diffuser.

(b) Rated conditions.

(c) Actual pressure. An observed or recorded measurement is 15 psi greater than actual pressure, due to purge-bias effect.

Figure 8-1. Average Engine Performance With Standard Deviation Values at Rated Conditions (Engines J-2025 Through J-2059) (Sheet 1 of 3)

Parameter	Unit of Measurement	Mean[(a)]	Standard Deviations (Percent)	
			Engine-to-Engine	Run-to-Run
OXIDIZER TURBOPUMP				
Engine inlet pressure	psia	39.00	--	--
Pump discharge pressure	psia	1,080.8	0.63	0.33
Developed head	ft	2,116.9	0.58	0.41
Volumetric flowrate (impeller flow)	gpm	2,907.4	0.17	0.16
Weight flowrate (includes leakage flow past PU valve with PU valve in fully closed position)	lb/sec	458.55	0.17	0.16
Horsepower	bhp	2,201.91	0.60	0.52
Speed	rpm	8,571.9	0.54	0.14
FUEL TURBOPUMP				
Engine inlet pressure	psia	30.00	--	--
Pump discharge pressure	psia	1,224.48	0.72	0.43
Developed head	ft	37,517.2	0.71	0.43
Volumetric flowrate	gpm	8,414.15	0.18	0.16
Weight flowrate	lb/sec	82.486	0.18	0.16
Horsepower	bhp	7,739.13	2.04	0.58
Speed	rpm	26,702.0	1.0	0.17
OXIDIZER TURBINE				
Inlet pressure (total)	psia	85.9	1.72	0.37
Outlet pressure (static)	psia	32.15	1.56	0.43

(a) Values include correction for runs made with diffuser.

Figure 8-1. Average Engine Performance With Standard Deviation Values at Rated Conditions (Engines J-2025 Through J-2059) (Sheet 2 of 3)

Parameter	Unit of Measurement	Mean(a)	Standard Deviations (Percent)	
			Engine-to-Engine	Run-to-Run
Inlet temperature	°R	1,229.54	1.36	1.73
	°F	769.86		
Outlet temperature	°R	1,071.83	1.41	1.04
	°F	612.15		
Auxiliary power available (30 bhp maximum)	bhp	15.00	--	--
FUEL TURBINE				
Inlet pressure (total)	psia	633.61	1.52	0.51
Outlet pressure (static)	psia	87.08	1.49	0.36
Inlet temperature	°R	1,659.7(b)	--	--
	°F	1,200.0		
Outlet temperature	°R	1,229.6	1.36	1.73
	°F	769.9		
GAS GENERATOR				
Chamber pressure (injector end)	psia	654.7	1.46	0.51
Oxidizer weight flowrate	lb/sec	3.4	1.08	0.51
Fuel weight flowrate	lb/sec	3.62	1.08	0.51
HYDROGEN TANK PRESSURIZATION				
Weight flowrate	lb/sec	0.80	--	--
Temperature	°R	(d)		
OXIDIZER TANK PRESSURIZATION				
Weight flowrate	lb/sec	1.8	--	--
Temperature	°R	(d)		

(a) Values include correction for runs made with diffuser.

(b) Rated conditions.

(d) Temperature values may be determined from applicable figures in this section.

Figure 8-1. Average Engine Performance With Standard Deviation Values at Rated Conditions (Engines J-2025 Through J-2059) (Sheet 3 of 3)

Parameter	Unit of Measurement	Mean	Standard Deviations	
			Engine-to-Engine	Run-to-Run
PROPELLANTS				
Oxidizer density	lb/cu ft	70.79		
Fuel density	lb/cu ft	4.40		
Fuel temperature	°R	37.156		
	°F	-422.547		
Oxidizer temperature	°R	164.476		
	°F	-295.212		
ENGINE				
Thrust	lb	230,000	1,696	598
Specific impulse	sec	424.9	0.75	0.66
Mixture ratio	O/F	5.50	0.031	0.010
Oxidizer weight flowrate (thrust chamber plus gas generator)	lb/sec	458.07	3.29	0.86
Fuel weight flowrate (thrust chamber plus gas generator)	lb/sec	83.29	0.63	0.19
Chamber pressure (injector end)	psia	780.2(a)	6.6	2.1
Area expansion ratio (corrected)		27.16:1	0.04	--
OXIDIZER TURBOPUMP				
Engine inlet pressure	psia	39.00	--	--
Pump discharge pressure	psia	1,108.5	12.69	3.19
Developed head	ft	2,172.0	25.9	6.4
Volumetric flowrate (impeller flow)	gpm	2,965.4	20.9	5.5
Weight flowrate	lb/sec	467.70	3.29	0.87
Horsepower	bhp	2,302.0	41.0	10.1
Speed	rpm	8,698.2	53.9	11.3

(a) Actual pressure. An observed or recorded measurement is 15 psi greater than actual pressure, due to purge-bias effect.

Figure 8-2. Average Engine Performance With Standard Deviation Values at Rated Conditions (Engines J-2060 and Subsequent) (Sheet 1 of 3)

Parameter	Unit of Measurement	Mean	Standard Deviations	
			Engine-to-Engine	Run-to-Run
FUEL TURBOPUMP				
Engine inlet pressure	psia	30.00	--	--
Pump discharge pressure	psia	1,251.3	13.39	3.55
Developed head	ft	38,336.9	406.2	107.7
Volumetric flowrate	gpm	8,587.5	64.7	19.3
Weight flowrate	lb/sec	84.19	0.63	0.19
Horsepower	bhp	8,587.5	178.2	38.9
Speed	rpm	27,167.2	264.3	56.3
OXIDIZER TURBINE				
Inlet pressure (total)	psia	89.3	2.2	0.4
Outlet pressure (static)	psia	33.65	0.64	0.21
Inlet temperature	°R	1,229.2	482.8	463.9
	°F	768.5	23.1	4.2
Outlet temperature	°R	1,071.2	478.7	464.7
	°F	611.5	19.0	5.0
Auxiliary power available (30 bhp maximum)	bhp	15.00		
FUEL TURBINE				
Inlet pressure (total)	psia	652.6	14.9	3.8
Outlet pressure (static)	psia	90.57	1.96	0.30
Inlet temperature	°R	1,659.7	482.0	466.0
	°F	1,200.0	22.3	6.3
Outlet temperature	°R	1,229.2	482.8	463.9
	°F	768.5	23.1	4.2
GAS GENERATOR				
Chamber pressure (injector end)	psia	682.0	15.6	3.9
Oxidizer weight flowrate	lb/sec	3.41	0.088	0.021
Fuel weight flowrate	lb/sec	3.63	0.102	0.020

Figure 8.2 Average Engine Performance With Standard Deviation Values at Rated Conditions (Engines J-2060 and Subsequent) (Sheet 2 of 3)

Parameter	Unit of Measurement	Mean	Standard Deviations	
			Engine-to-Engine	Run-to-Run
HYDROGEN TANK PRESSURIZATION				
Weight flowrate	lb/sec	0.90		
Temperature	°R	(b)		
OXIDIZER TANK PRESSURIZATION				
Weight flowrate	lb/sec	2.10		
Temperature	°R	(b)		

(b) Temperature values may be determined from applicable figures in this section.

Figure 8-2. Average Engine Performance With Standard Deviation Values at Rated Conditions (Engines J-2060 and Subsequent) (Sheet 3 of 3)

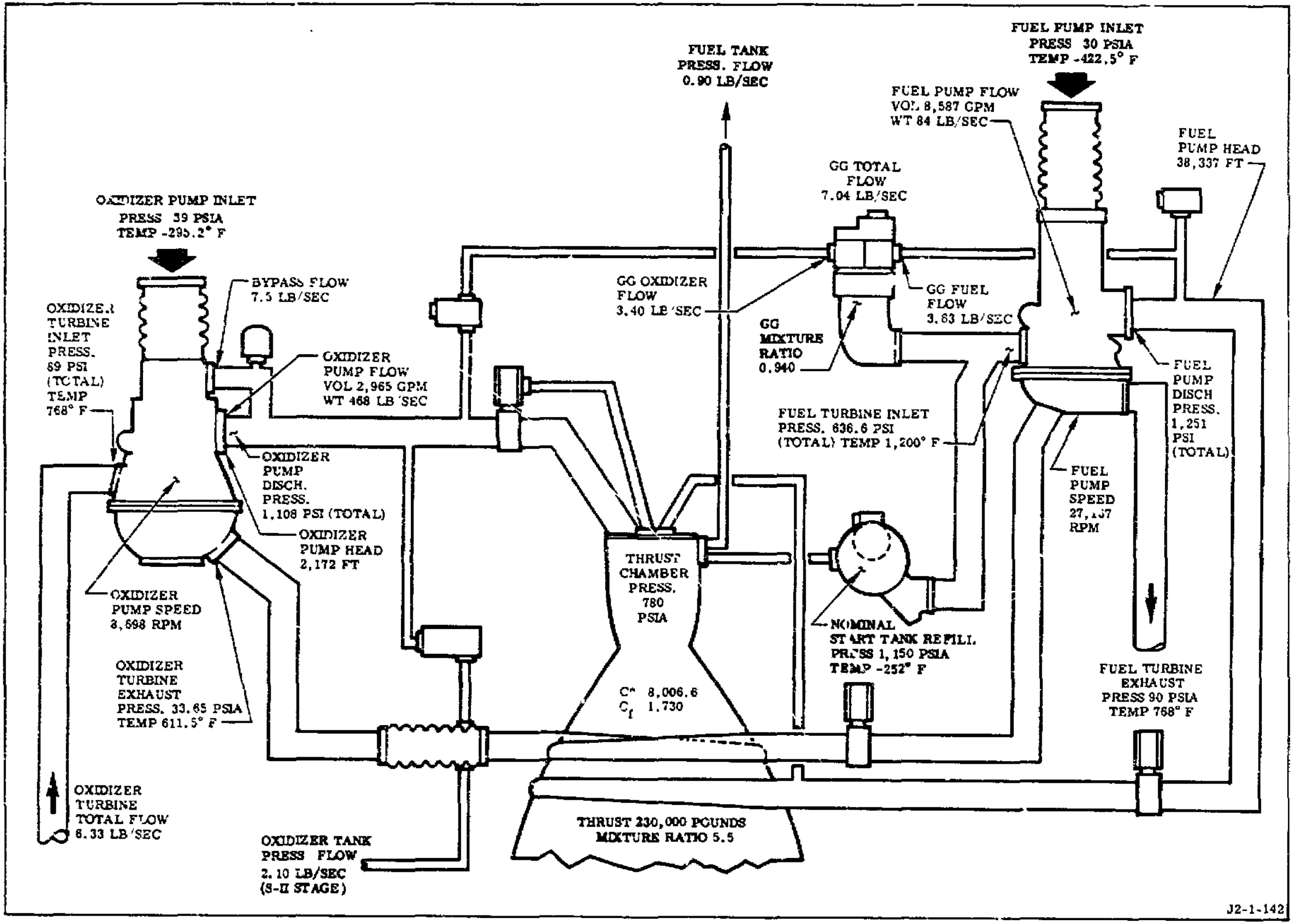


Figure 8-3. Average Engine Performance Schematic (Engines J-2060 and Subsequent)

8-9. PERFORMANCE VARIATIONS RESULTING FROM OFF-NOMINAL CONDITIONS AND PROPELLANT UTILIZATION VALVE OPERATION.

8-10. Variations in specific impulse and thrust versus altitude are defined in figures 8-4 through 8-7. Variations in thrust and specific impulse versus engine mixture ratio (MR) are defined in figures 8-8 through 8-11. A typical curve of engine mixture ratio versus propellant utilization (PU) valve voltage ratio for engines supplied with a PU valve without a rotated deflector is shown in figure 8-12. On engines incorporating MD283 change, the PU valve deflector has been rotated 30 degrees counterclockwise. Curves of thrust, specific impulse, and mixture ratio versus PU valve voltage ratio for engines supplied with a PU valve with the rotated deflector are shown in figures 8-12A through 8-12C. If MD283 change is incorporated after engine acceptance testing, the PU curves in the Engine Log Book are invalidated and must be replaced with the curves in figures 8-12A through 8-12C. The engine propellant utilization (PU) system is designed for a mixture ratio control of 1.0 mixture ratio units (MRU).

8-11. Curves of specific impulse, thrust, and mixture ratio versus mixture ratio control valve position for engines incorporating MD366 or MD371 change, are shown in figures 8-12D through 8-12F. The relationship between mixture ratio control valve gate angle and mixture ratio control valve position (telemetry volts DC) is shown in figure 8-12G.

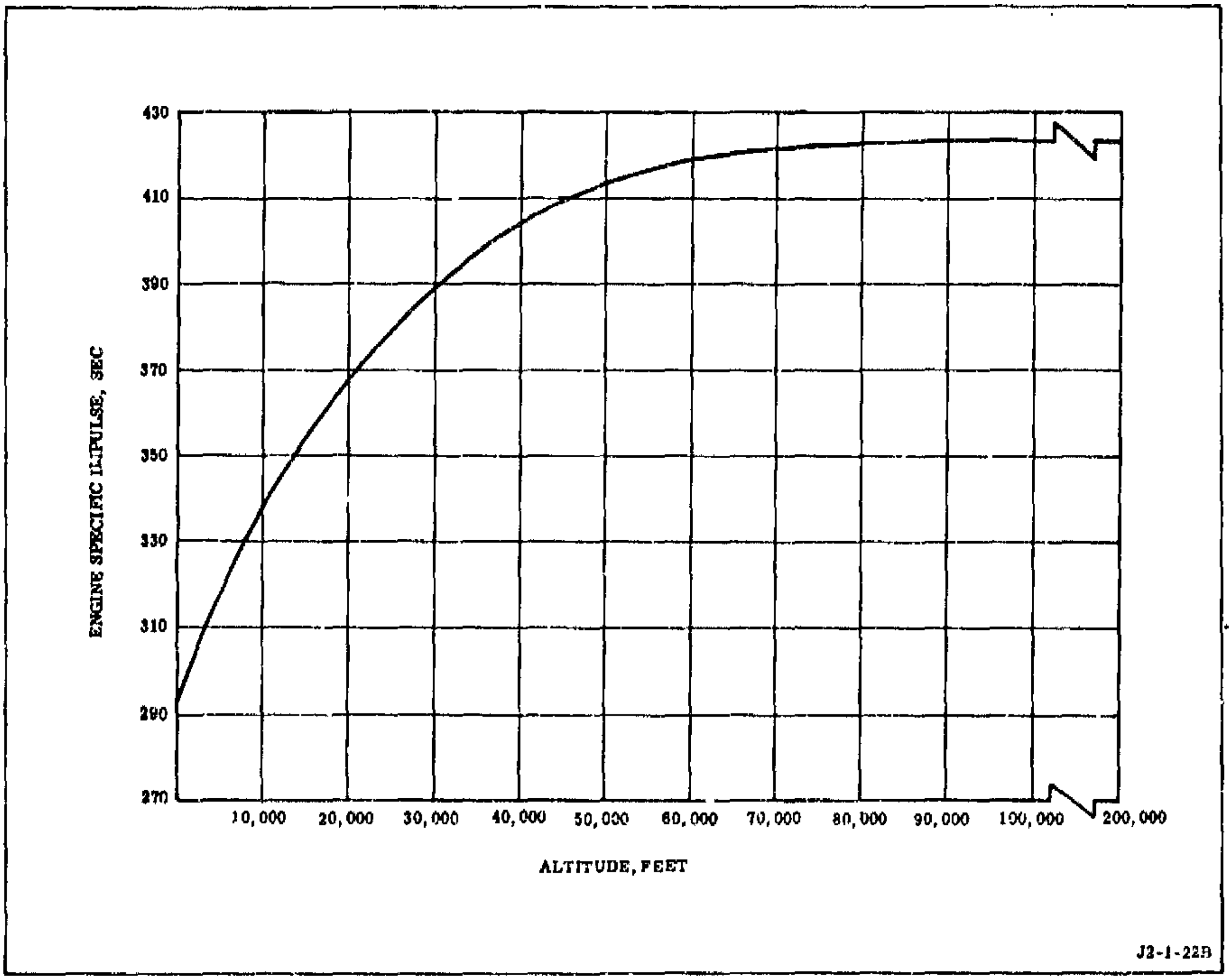


Figure 8-4. Specific Impulse Versus Altitude (Engines J-2025 Through J-2059)

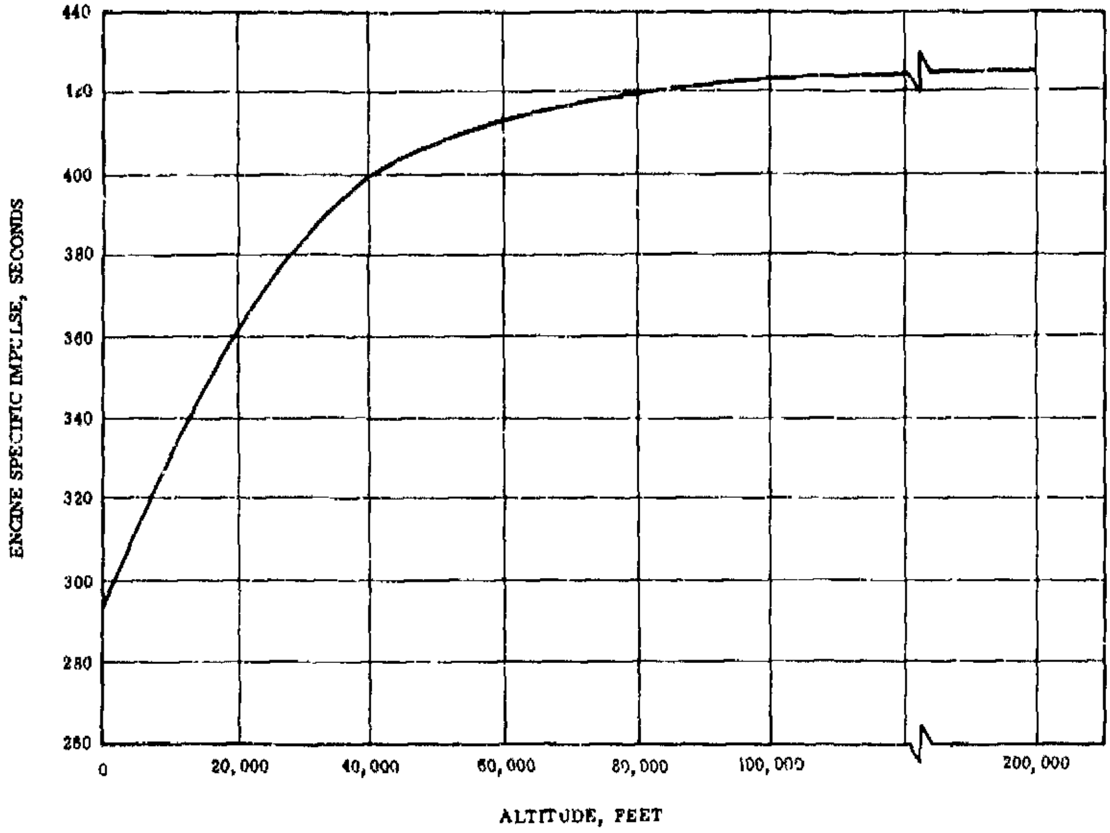


Figure 8-5. Specific Impulse Versus Altitude (Engines J-2060 and Subsequent)

8-12. Performance variation caused by off-nominal conditions may be determined using the engine influence coefficients presented in figures 8-19 and 8-20. When helium is used as the vehicle oxidizer tank pressurant (SIVB stage), engine performance changes must be determined using the helium flow influence coefficients in figures 8-19 and 8-20. For engines supplying oxidizer as the vehicle oxidizer tank pressurant (SII stage), engine performance changes must be determined using the correction curve in figure 8-21 with the influence coefficients in figures 8-19 and 8-20. The helium flow influence coefficient column is not used.

8-13. A Mixture ratio variation capability has been provided in the PU valve. The effect of varying mixture ratio on engine performance may be calculated by utilizing the influence coefficients in figures 8-19 and 8-20. Figures 8-12 and 8-12C show the relationship between PU valve voltage ratio and engine mixture ratio. Thrust chamber propellant flowrates when controlled by differing PU valve settings, including all expected variations, are shown in figures 8-13 and 8-14. Gas generator propellant flowrates when controlled by differing PU valve settings, including all expected variations, are shown in figures 8-15 and 8-16.

8-13A. The PU valve position is expressed in terms of voltage ratio. Voltage ratio is obtained from the telemetry potentiometer signal and is calculated from the formula

$$\text{Voltage ratio} = \frac{\text{Potentiometer output in volts}}{\text{Potentiometer input in volts}}$$

When the PU valve position is related to engine performance data, the valve position also may be defined in terms of nominal, maximum, and minimum propellant utilization. The PU valve is in the nominal position when the control potentiometer wiper is in contact with the tap on the control potentiometer. Maximum propellant utilization occurs when the PU valve is fully closed, and minimum propellant utilization occurs when the PU valve is fully open. The following data illustrates the relationships between propellant utilization, valve position, and position indication in voltage ratio:

Propellant Utilization	Valve Position in Degrees from Nominal	Valve Position in Voltage Ratio
Maximum	32.5 (closed)	0.025
Nominal	0 (--)	0.540
Minimum	27.5 (open)	0.975

Figure 8-6 deleted.

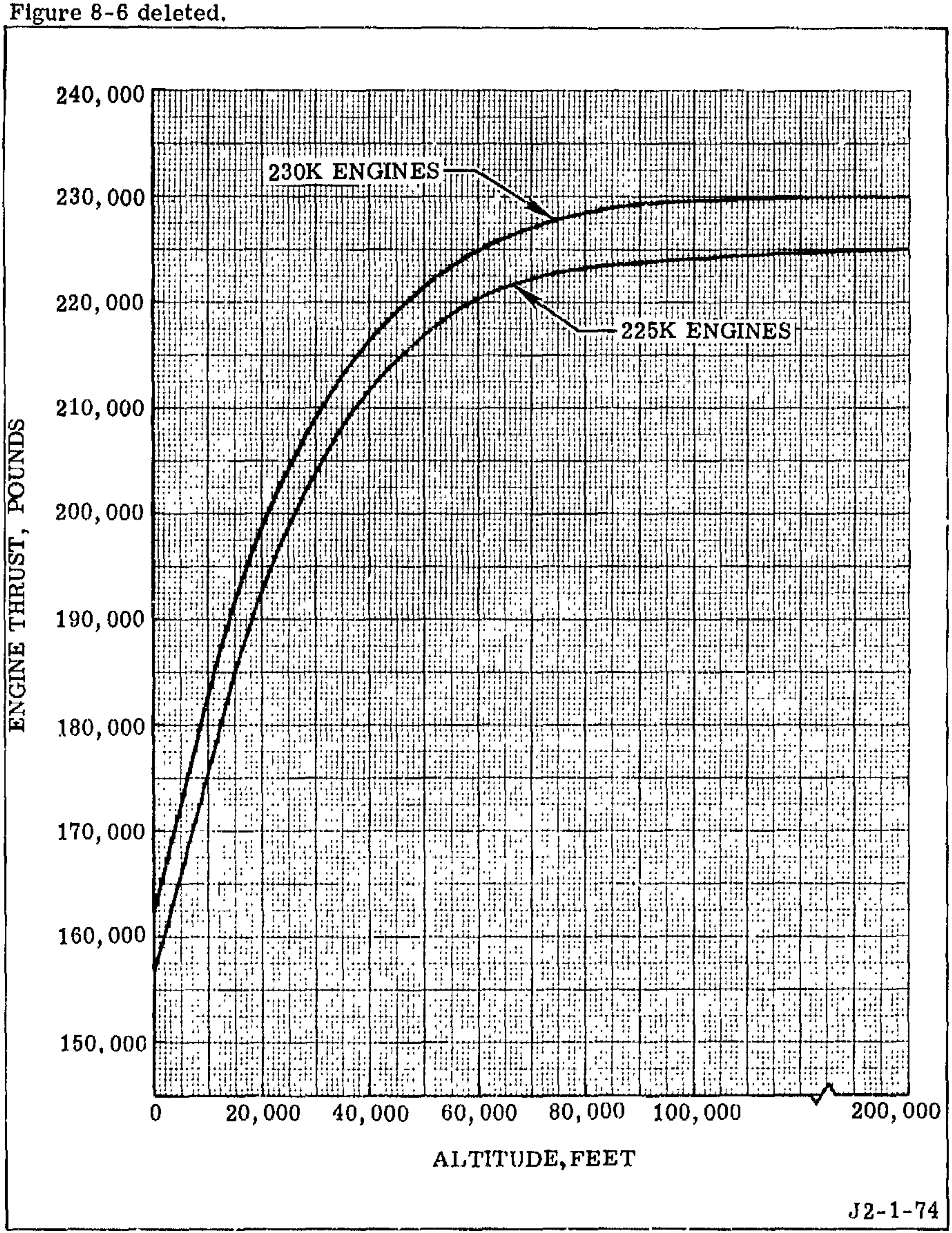


Figure 8-7. Thrust Versus Altitude

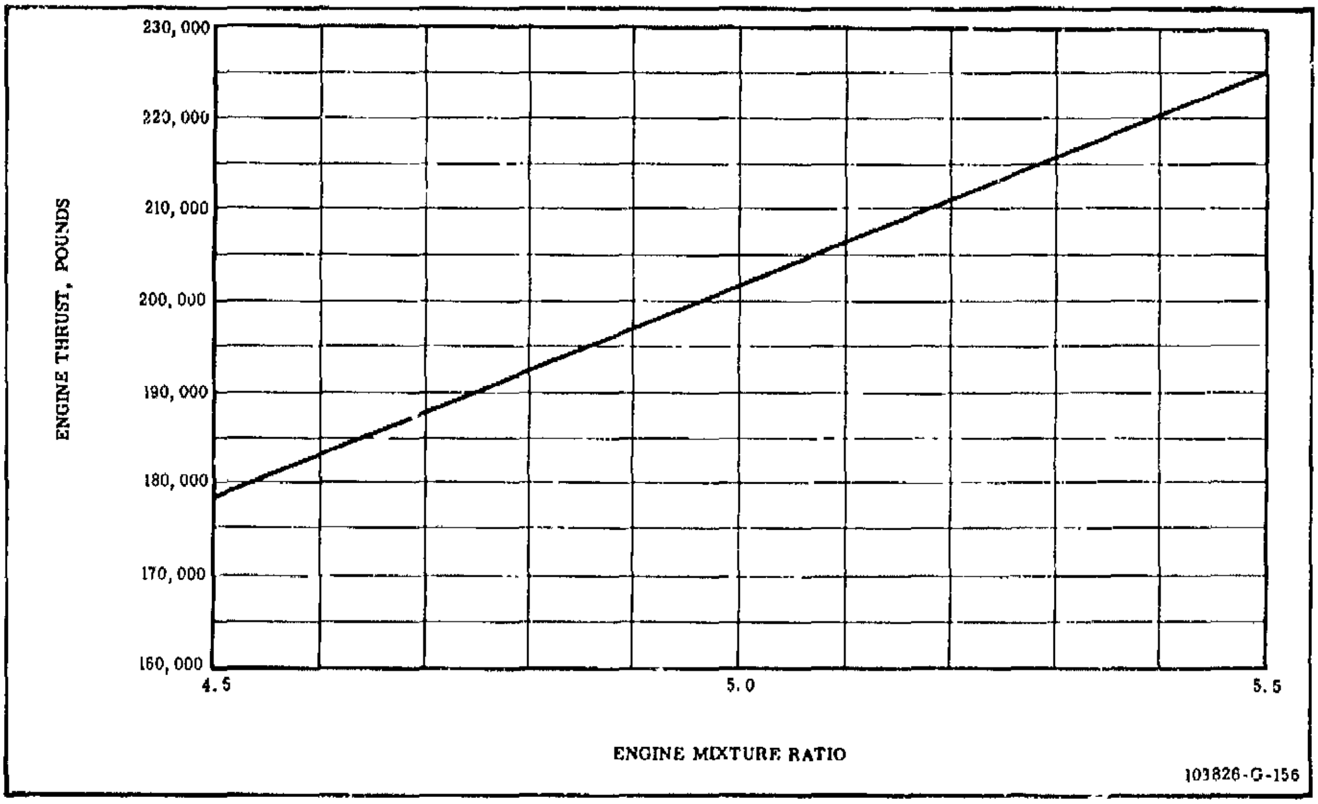


Figure 8-8. Engine Thrust Versus Engine Mixture Ratio for Variation in PU Valve Position (Altitude) (Engines J-2025 Through J-2059)

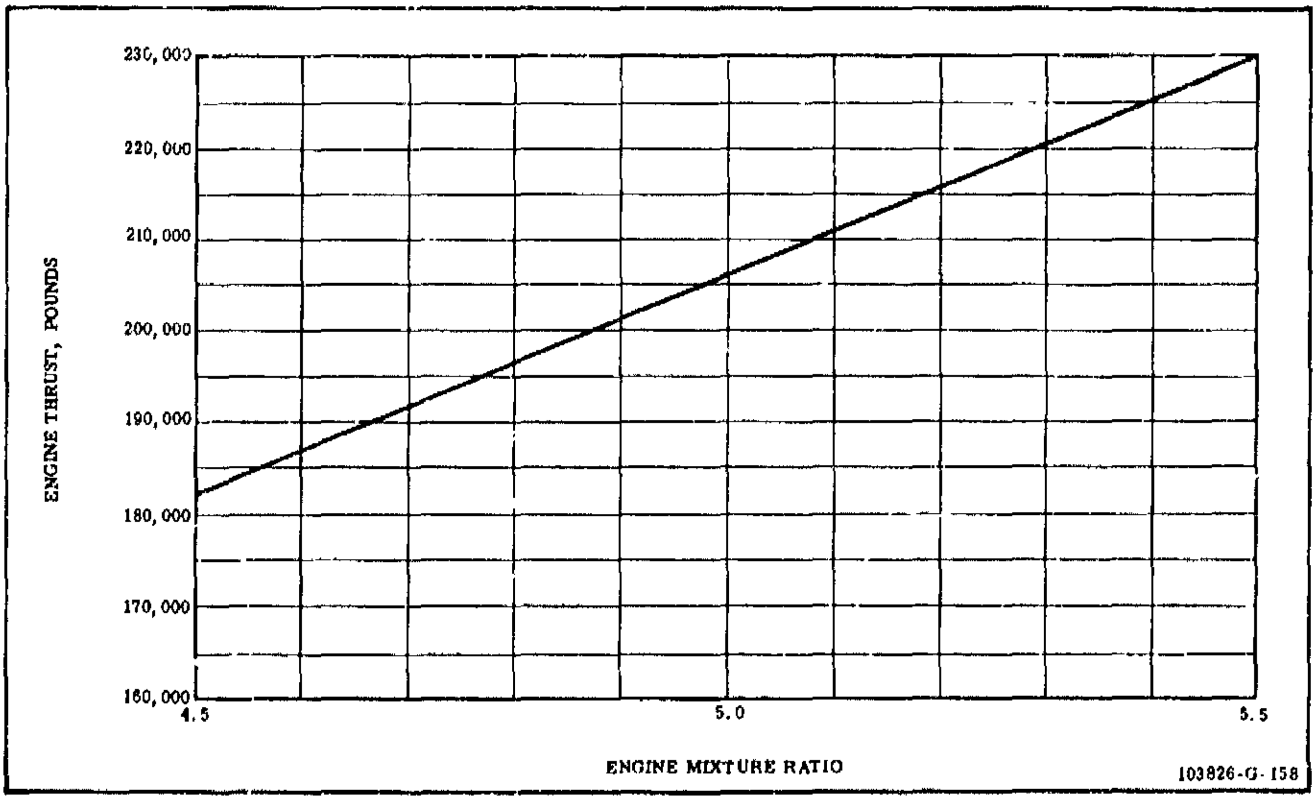


Figure 8-9. Engine Thrust Versus Engine Mixture Ratio for Variation in PU Valve Position (Altitude) (Engines J-2060 and Subsequent)

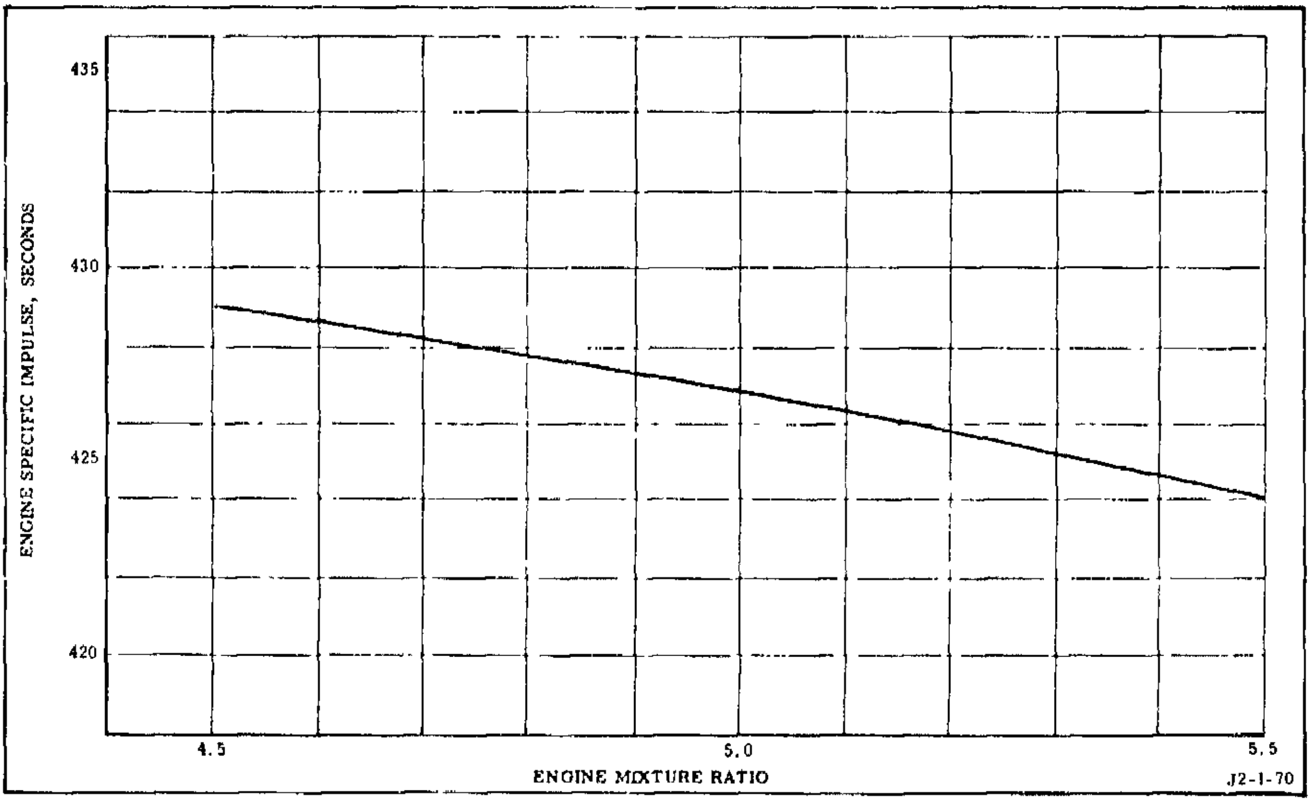


Figure 8-10. Engine Specific Impulse Versus Engine Mixture Ratio for Variation in PU Valve Position (Altitude) (Engines J-2025 Through J-2059)

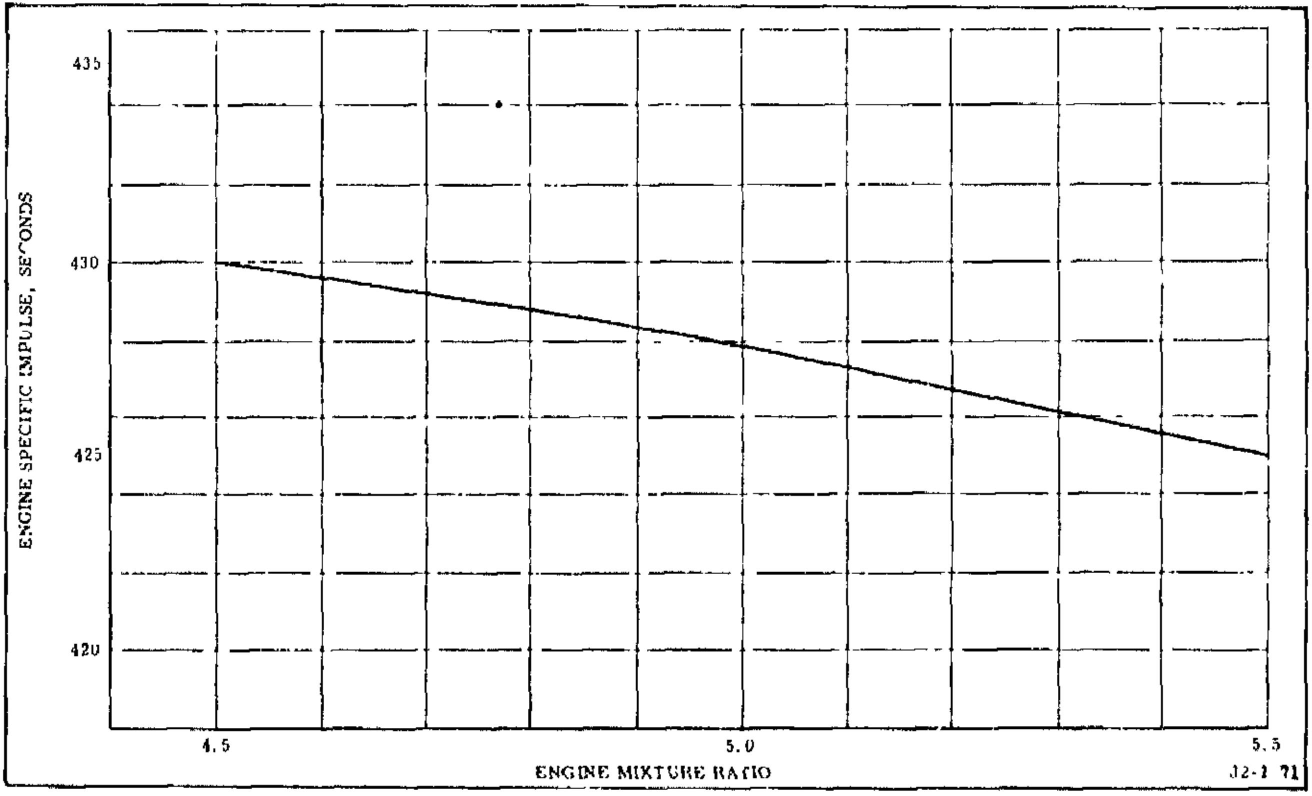


Figure 8-11. Engine Specific Impulse Versus Engine Mixture Ratio for Variation in PU Valve Position (Altitude) (Engines J-2060 and Subsequent)

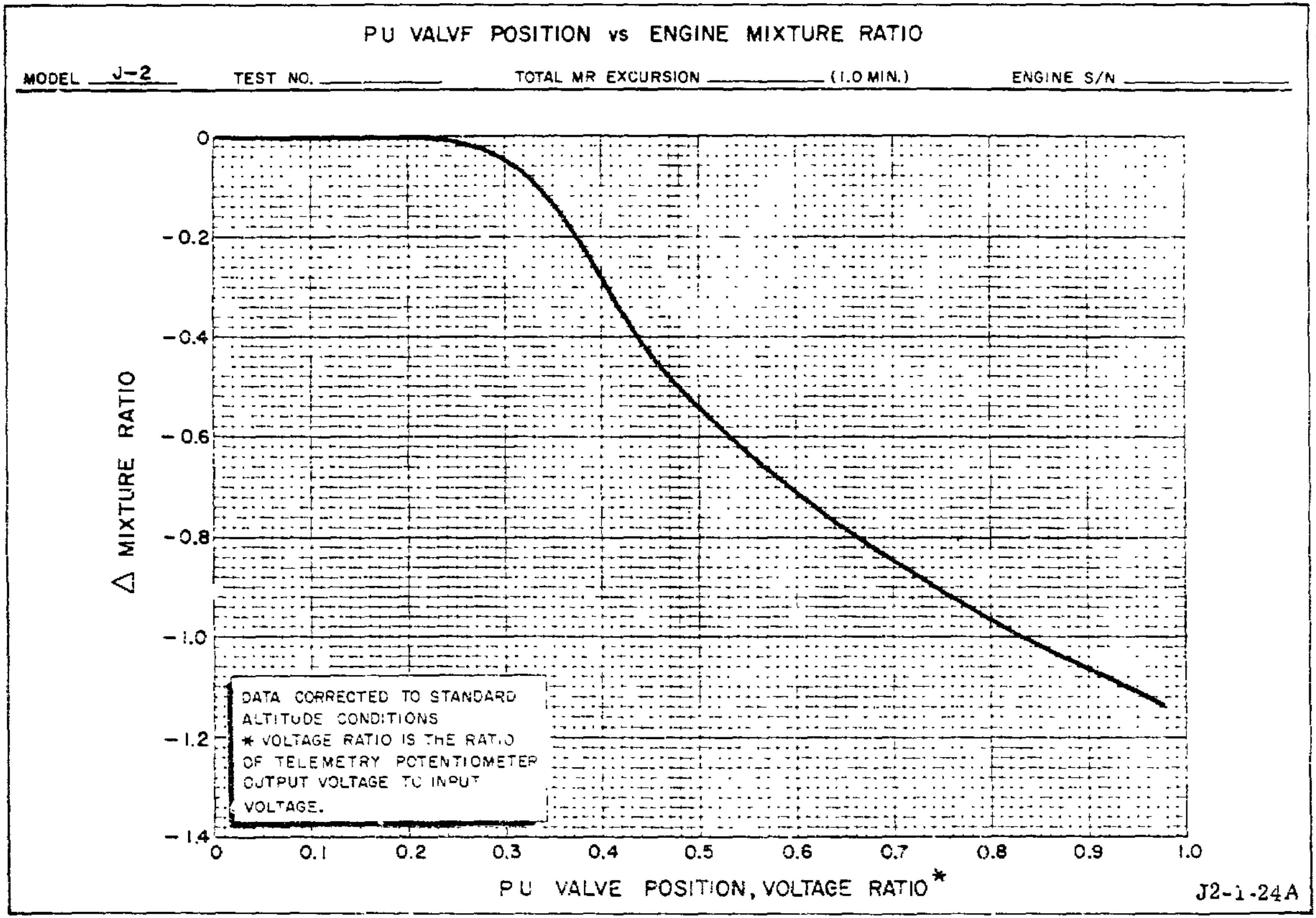
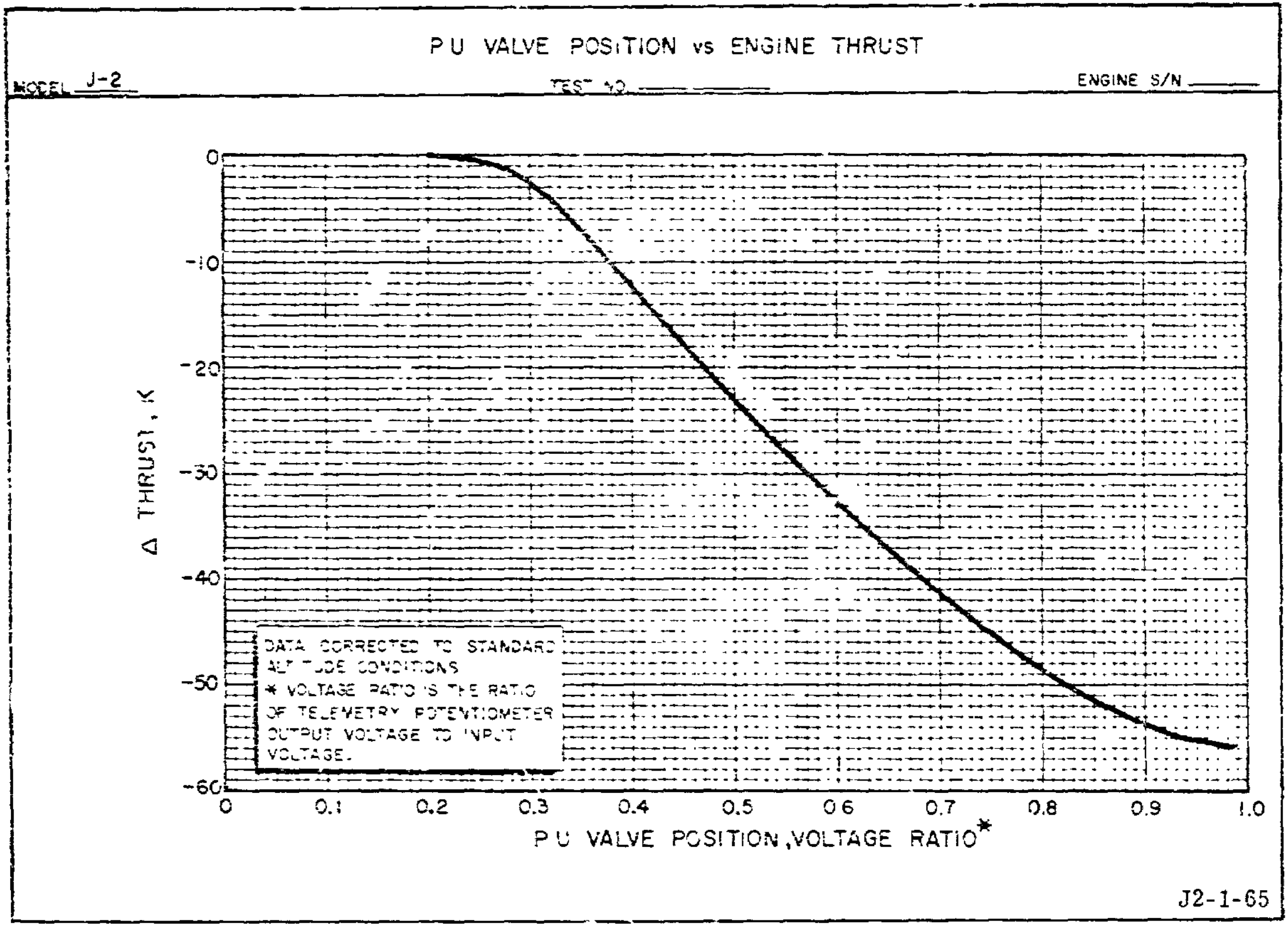
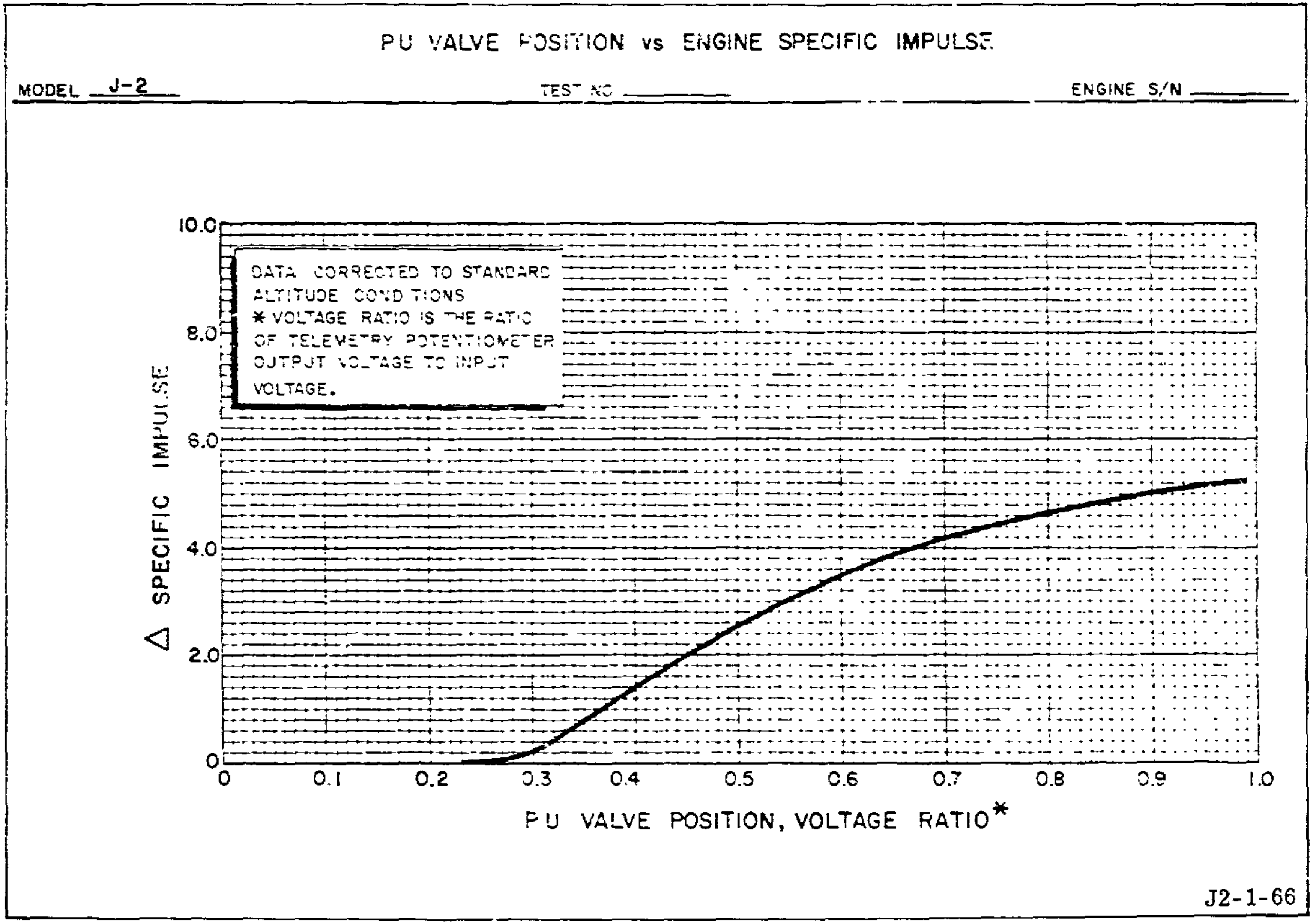


Figure 8-12. Differential Mixture Ratio Versus Propellant Utilization Valve Position for Valve Without Rotated Deflector



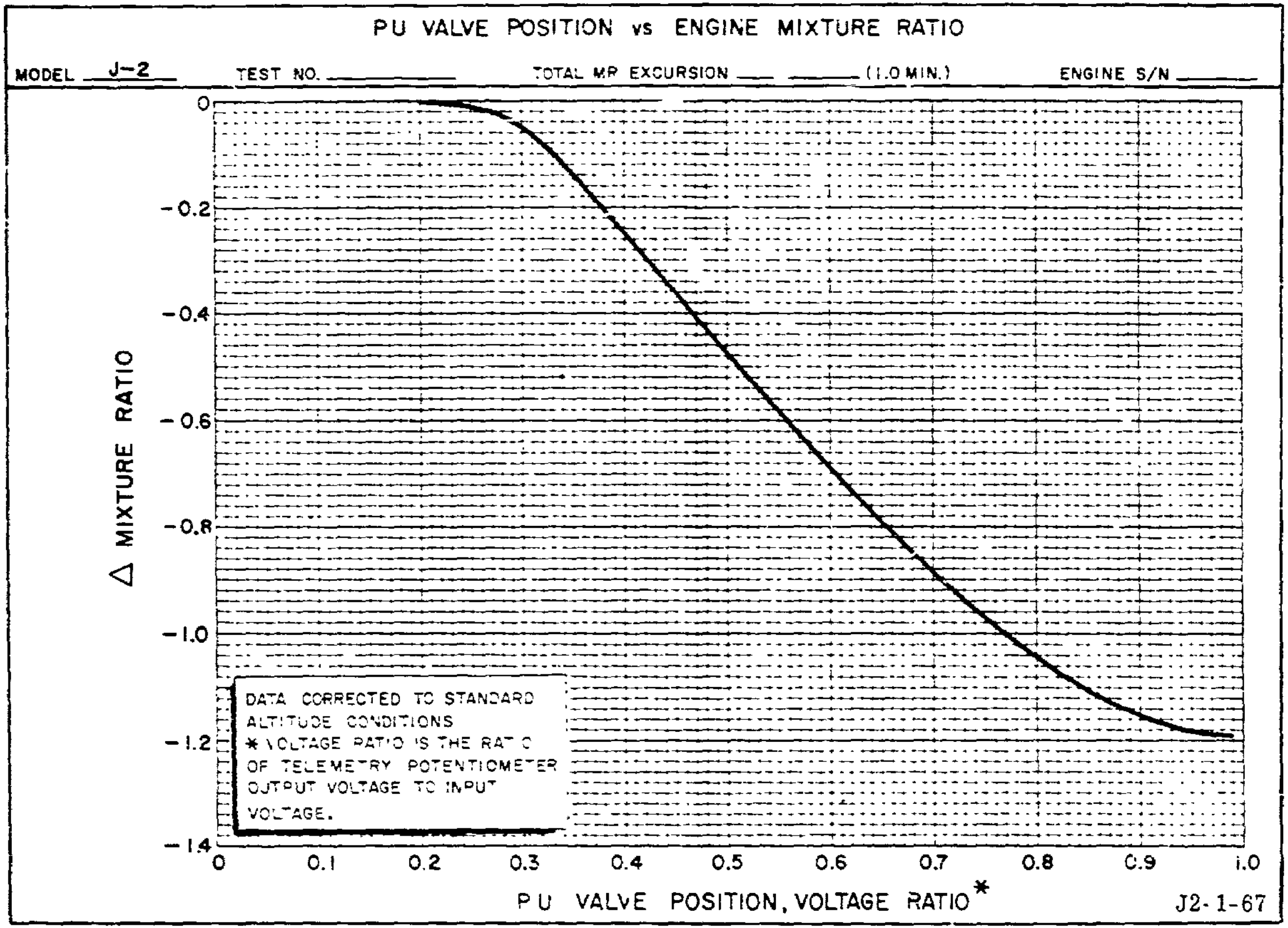
DATA CORRECTED TO STANDARD ALTITUDE CONDITIONS
* VOLTAGE RATIO IS THE RATIO OF TELEMETRY POTENTIOMETER OUTPUT VOLTAGE TO INPUT VOLTAGE.

Figure 8-12A. Differential Thrust Versus Propellant Utilization Valve Position for Valve With Rotated Deflector



DATA CORRECTED TO STANDARD ALTITUDE CONDITIONS
* VOLTAGE RATIO IS THE RATIO OF TELEMETRY POTENTIOMETER OUTPUT VOLTAGE TO INPUT VOLTAGE.

Figure 8-12B. Differential Specific Impulse Versus Propellant Utilization Valve Position for Valve With Rotated Deflector



DATA CORRECTED TO STANDARD ALTITUDE CONDITIONS
* VOLTAGE RATIO IS THE RATIO OF TELEMETRY POTENTIOMETER OUTPUT VOLTAGE TO INPUT VOLTAGE.

Figure 8-12C. Differential Mixture Ratio Versus Propellant Utilization Valve Position for Valve With Rotated Deflector

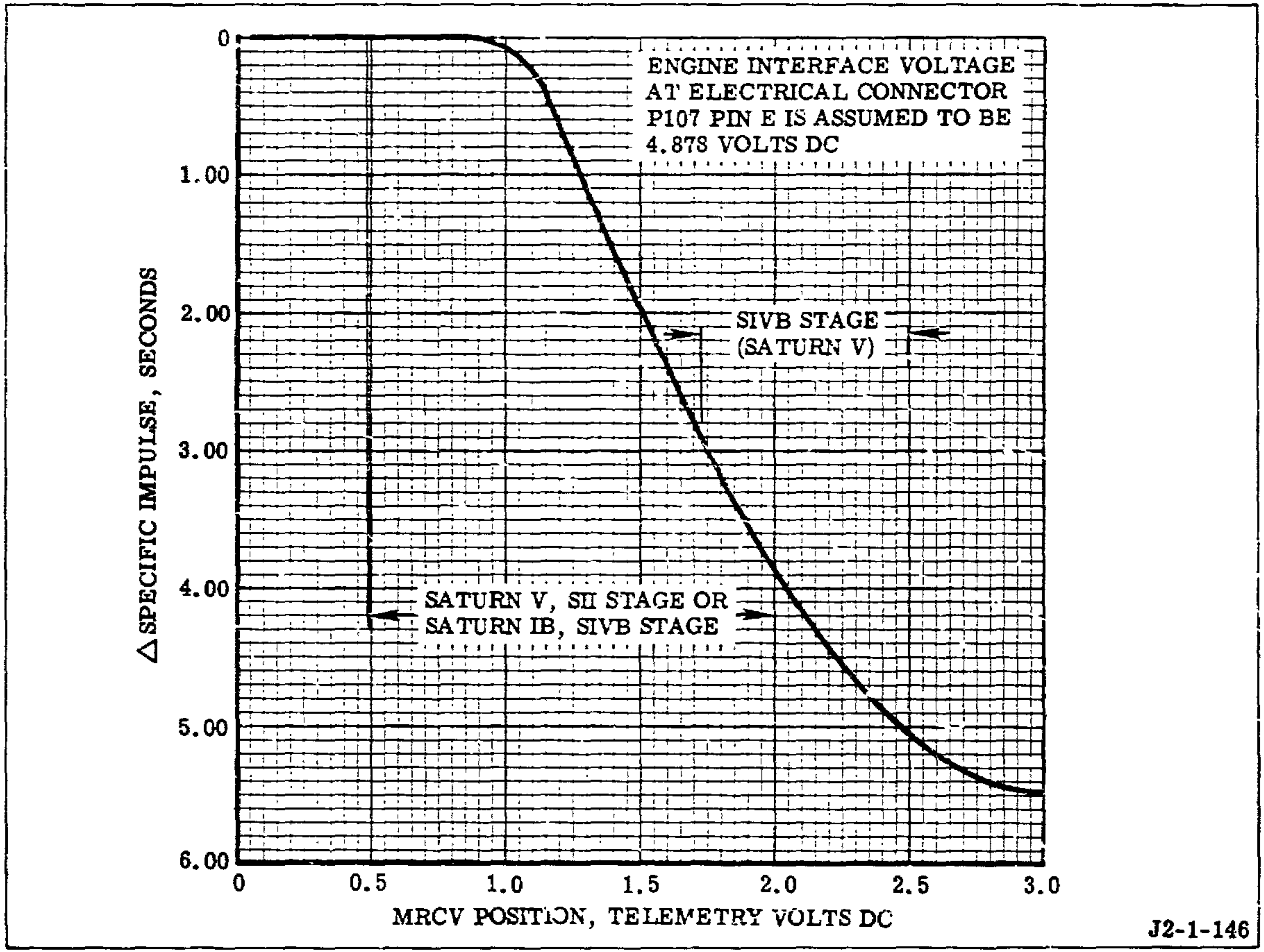
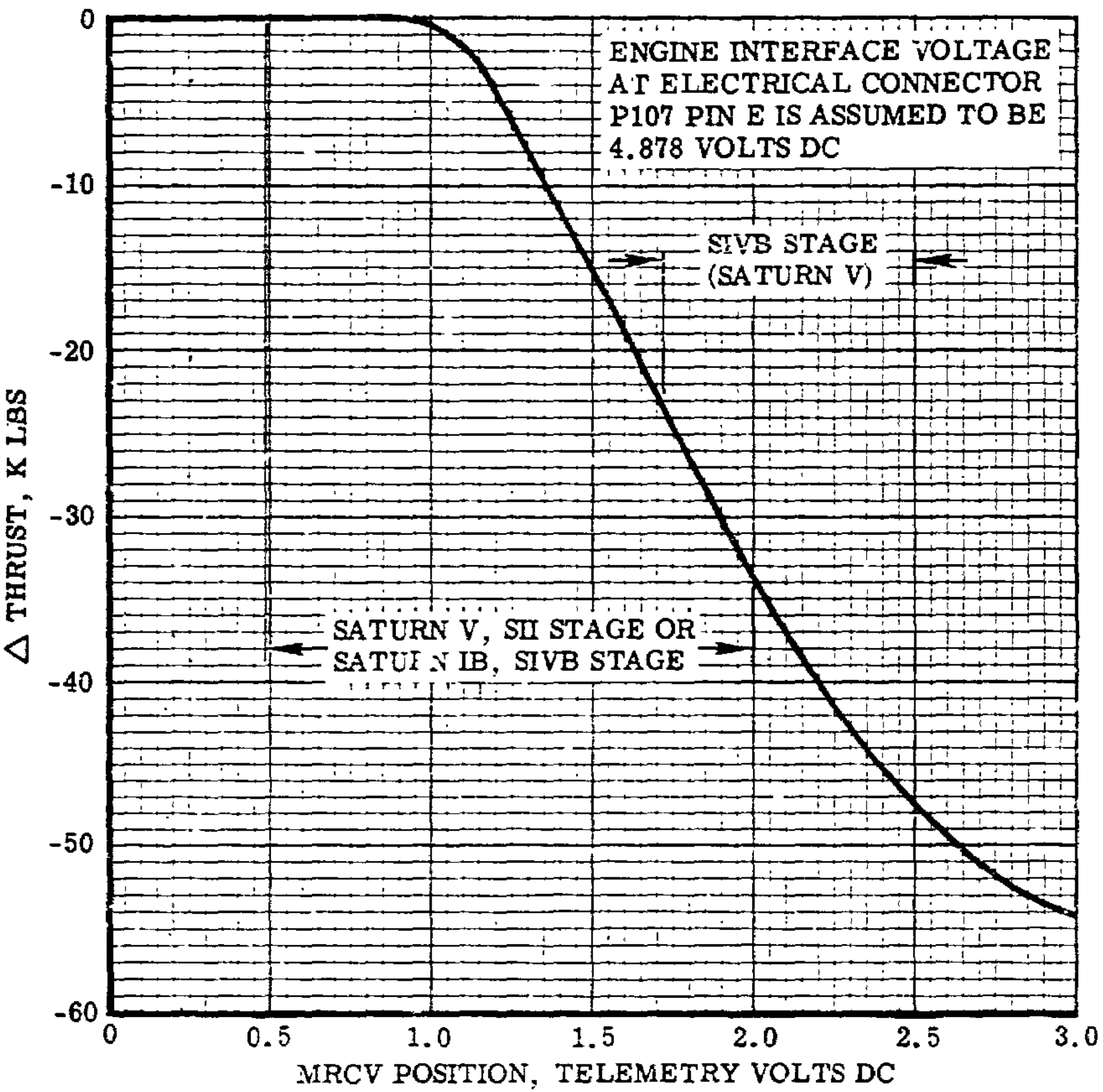
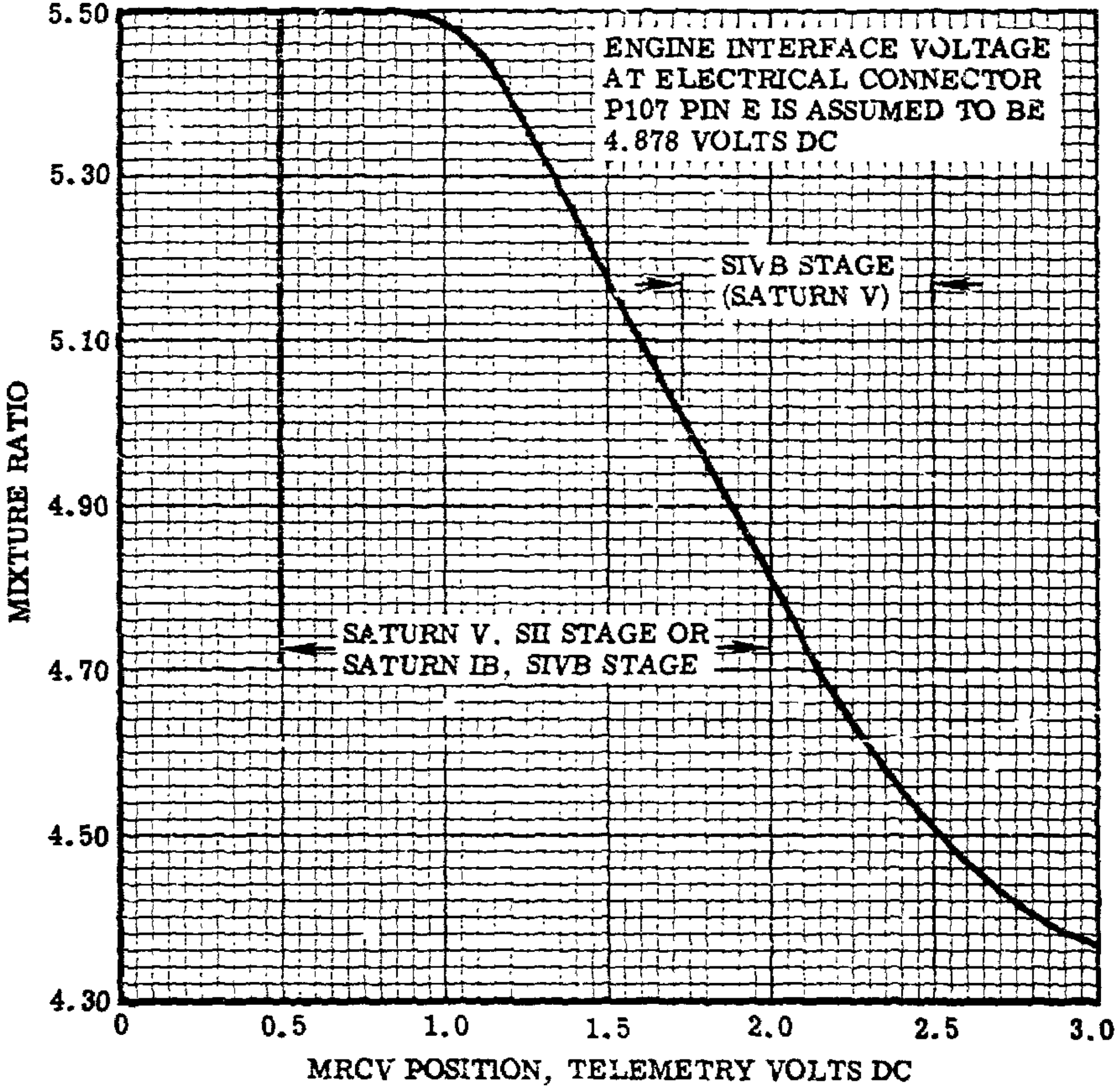


Figure 8-12D. Engine Delta Specific Impulse Versus Mixture Ratio Control Valve Position



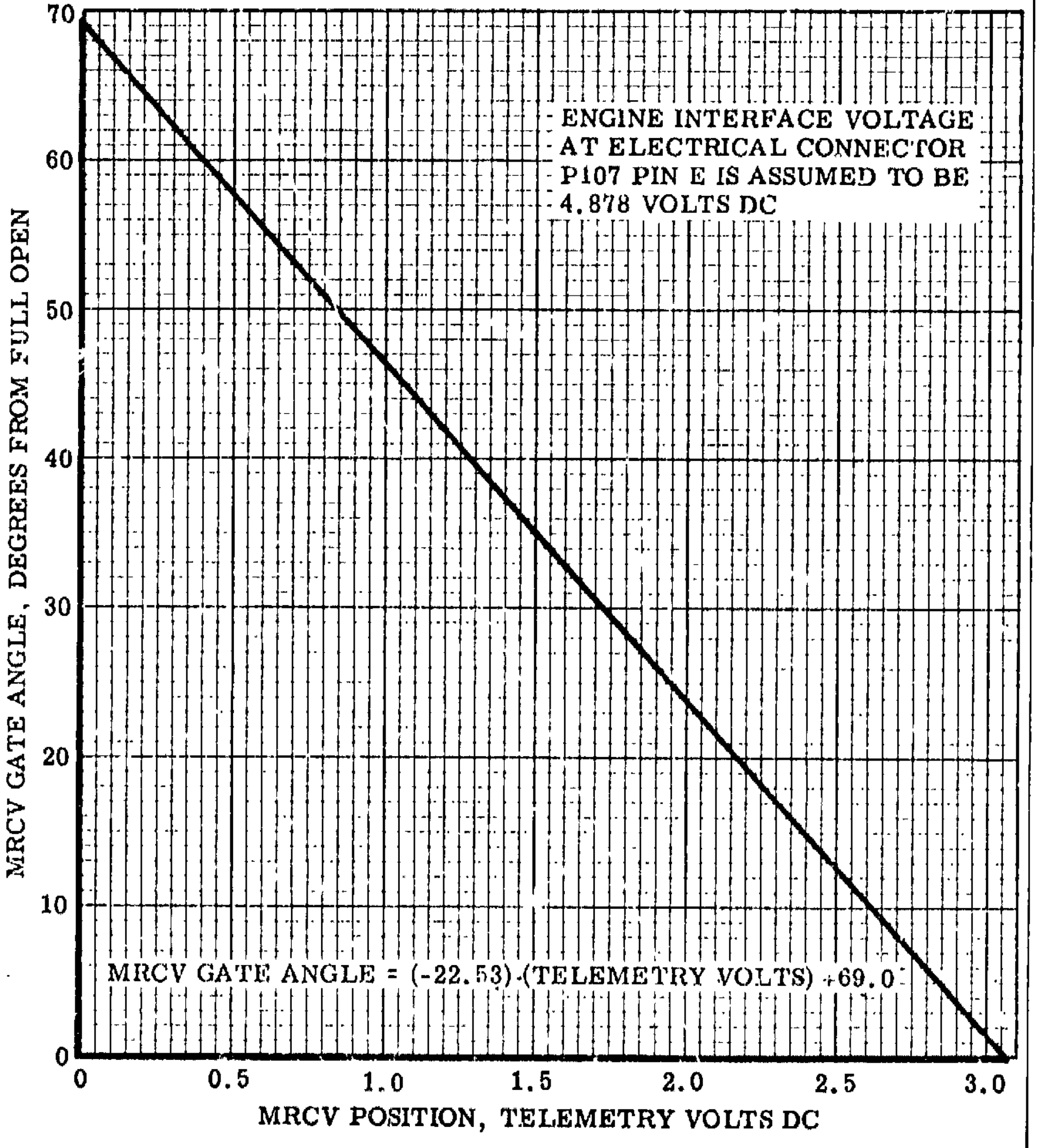
J2-1-147

Figure 8-12E. Engine Delta Thrust Versus Mixture Ratio Control Valve Position



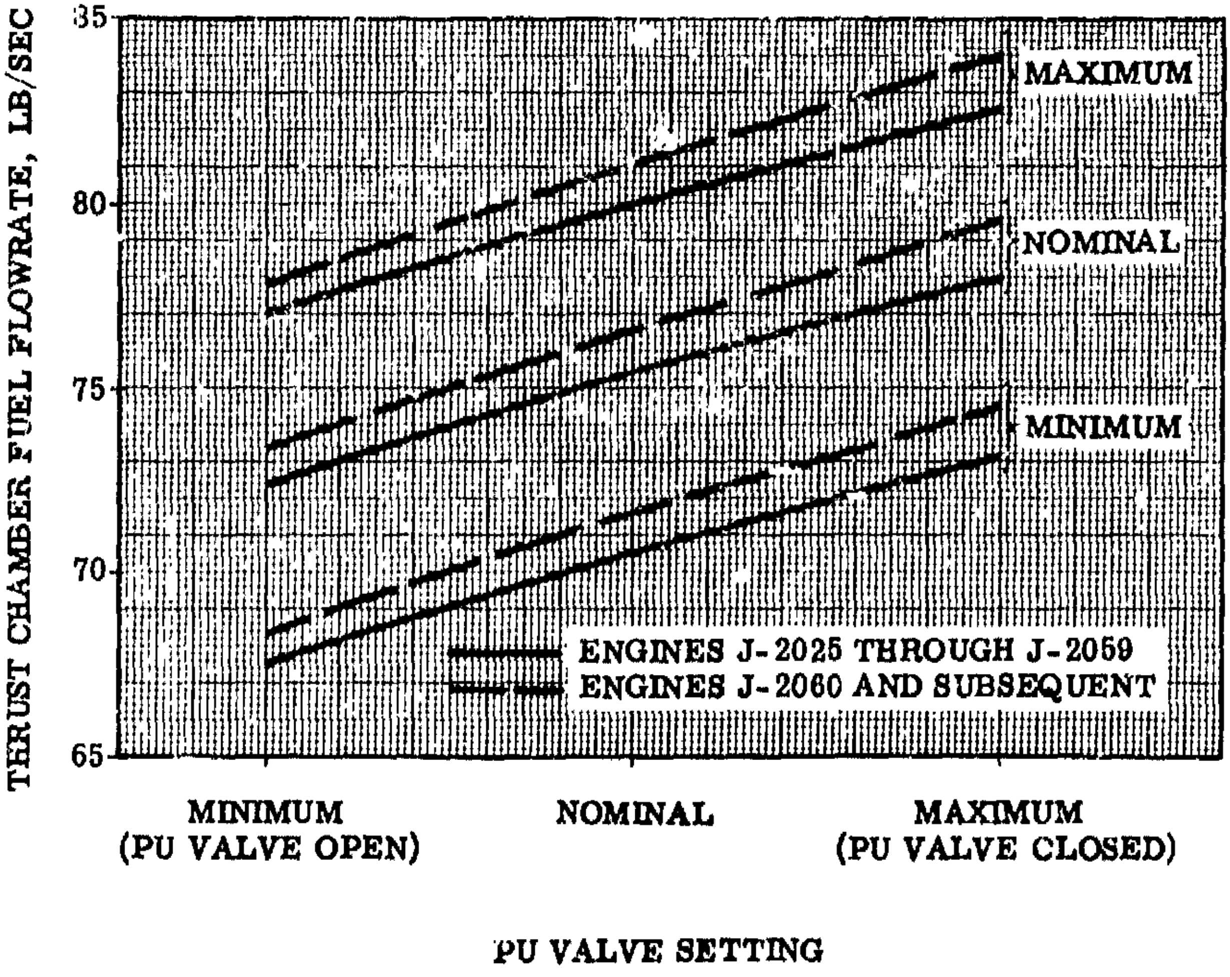
J2-1-149

Figure 8-12F. Engine Nominal Mixture Ratio Versus Mixture Ratio Control Valve Position



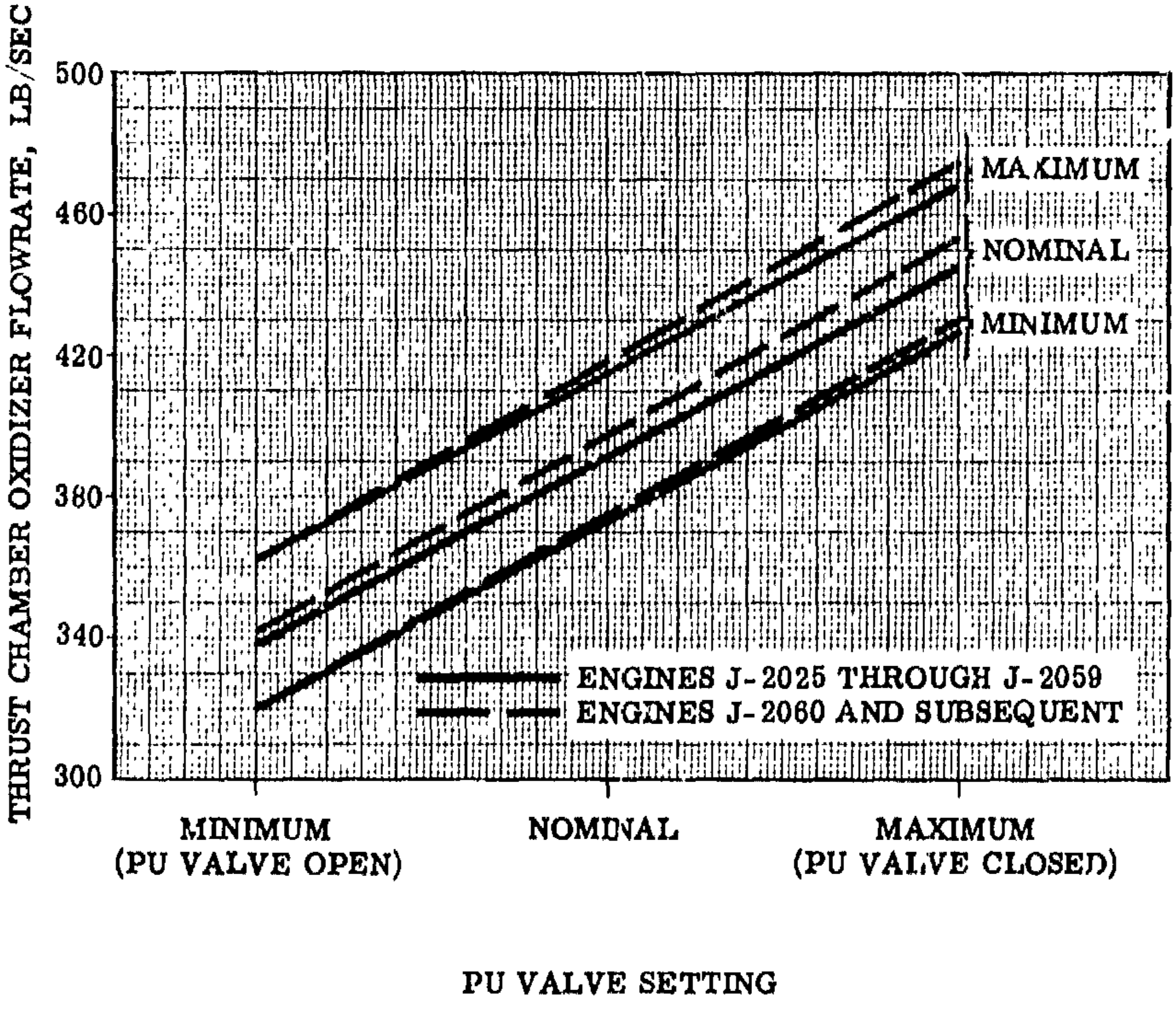
J2-1-148

Figure 8-12G. Mixture Ratio Control Valve Gate Angle Versus Mixture Ratio Control Valve Position



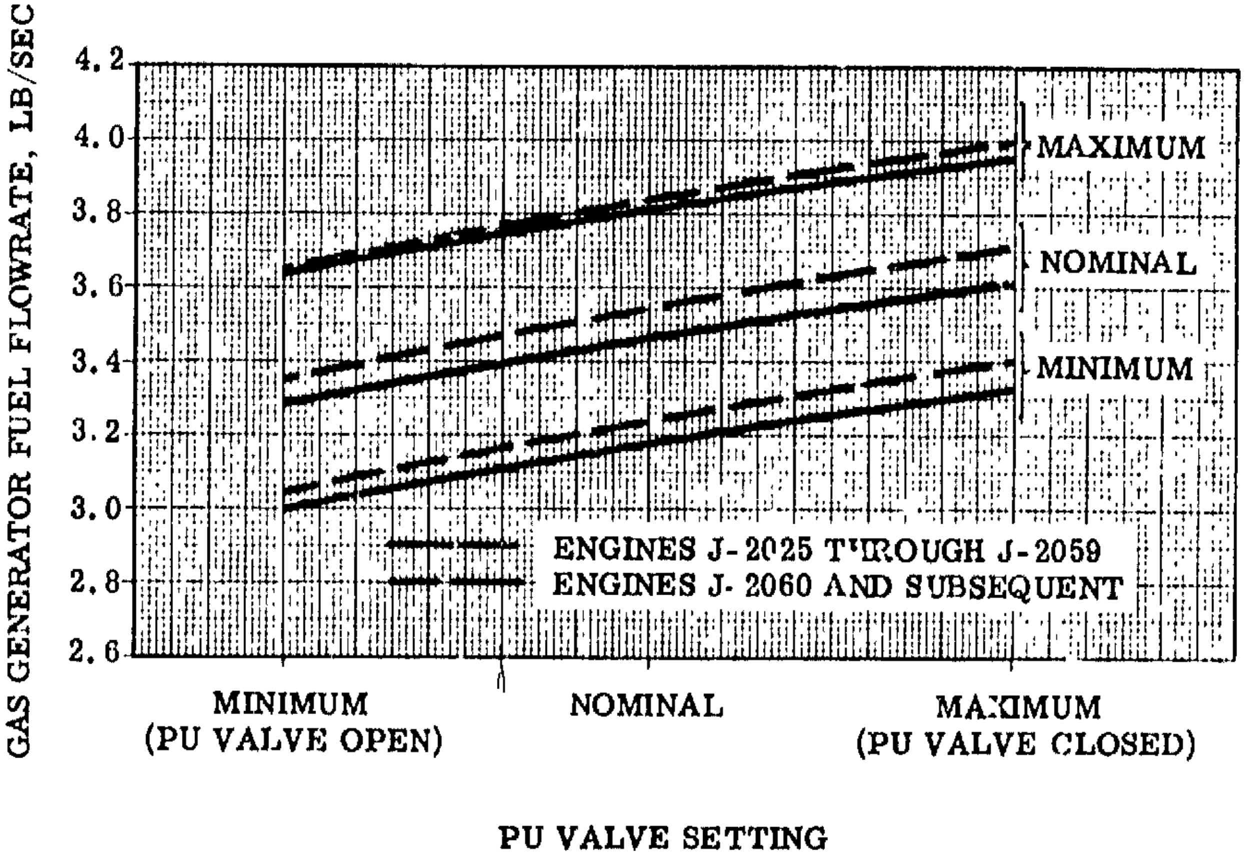
J2-1-25

Figure 8-13. Thrust Chamber Fuel Flowrate Versus Propellant Utilization Valve Setting



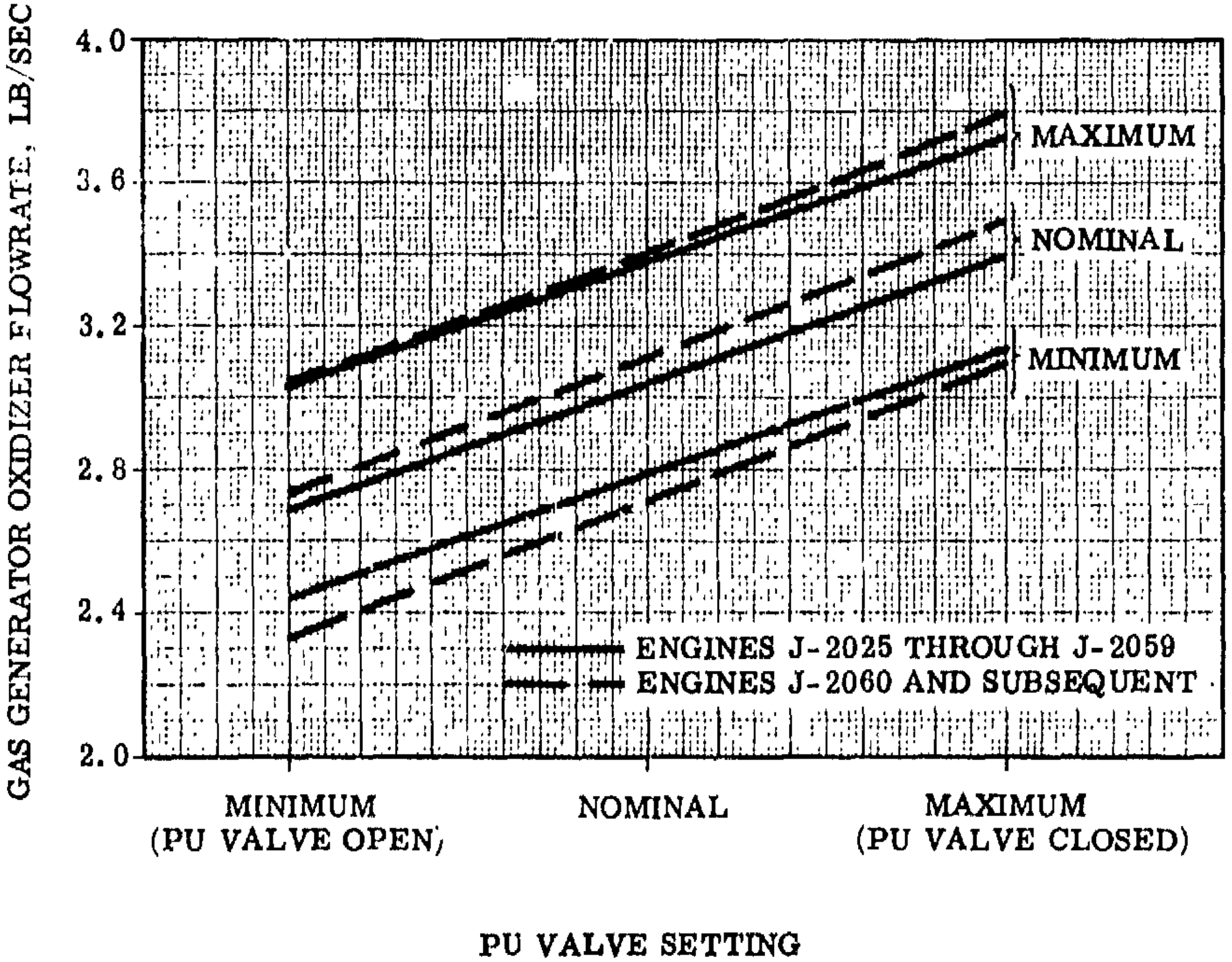
J2-1-26

Figure 8-14. Thrust Chamber Oxidizer Flowrate Versus Propellant Utilization Valve Setting



J2-1-27

Figure 8-15. Gas Generator Fuel Flowrate Versus Propellant Utilization Valve Setting



J2-1-28

Figure 8-16. Gas Generator Oxidizer Flowrate Versus Propellant Utilization Valve Setting

8-14. TRANSFER FUNCTION FOR ENGINE THRUST RESPONSE TO PU VALVE MOVEMENT. (See figures 8-17 and 8-18.)

8-15. The transfer function between engine thrust and PU valve position is given by the following equation:

$$\frac{\partial F}{\partial P} = \frac{-G\left[\left(\frac{S}{15.92}\right)^2 + 2 \times 0.039\left(\frac{S}{15.92}\right) + 1\right]}{\left[\frac{S}{9.79} + 1\right]\left[\left(\frac{S}{26.49}\right)^2 + 2 \times 0.56\left(\frac{S}{26.49}\right) + 1\right]}\ \frac{\text{pounds}}{\text{degree}} \qquad (1)$$

NOTE

S is the Laplace transform operator.

Since PU valve resistance is a nonlinear function of valve position, the steady-state gain (g) varies nonlinearly with valve position. For perturbations of the valve about any position, the steady-state gain has been calculated (figure 8-17). The dynamics of the engine system are nearly constant over the PU operating range, and the poles and zeroes of the above equation do not change significantly at the extreme valve positions. The gain and phase of the transfer function for 0-30 cps is shown in figure 8-18 for linear perturbations at zero degrees from the center tap.

8-16. INFLUENCE COEFFICIENTS.

8-17. The engine influence coefficients (figures 8-19 and 8-20) result from a linearized solution of a set of steady-state equations which describe the operation of an engine. Each influence coefficient is expressed in percentage form and represents the effect upon an engine dependent variable of a +1% change in an engine independent variable. A coefficient preceded by a positive (+) sign, or no sign, indicates that an increase in the independent variable results in an increase in the dependent variable; a coefficient preceded by a negative (-) sign indicates that an increase in the independent variable results in a decrease in the dependent variable.

8-18. Influence coefficients possess adequate accuracy over the entire design operating range of the engine. The c* correction shown in figures 8-19 and 8-20 is optional for increased accuracy and is to be used with the other independent variables to compute changes in the dependent variables because of c* nonlinearity in the system.

8-19. The following information is required for the sample calculation to determine engine thrust using influence coefficients from figure 8-19 and the listed operating conditions.

a. Fuel temperature: 38.00°R.

b. Oxidizer temperature: 165.0°R.

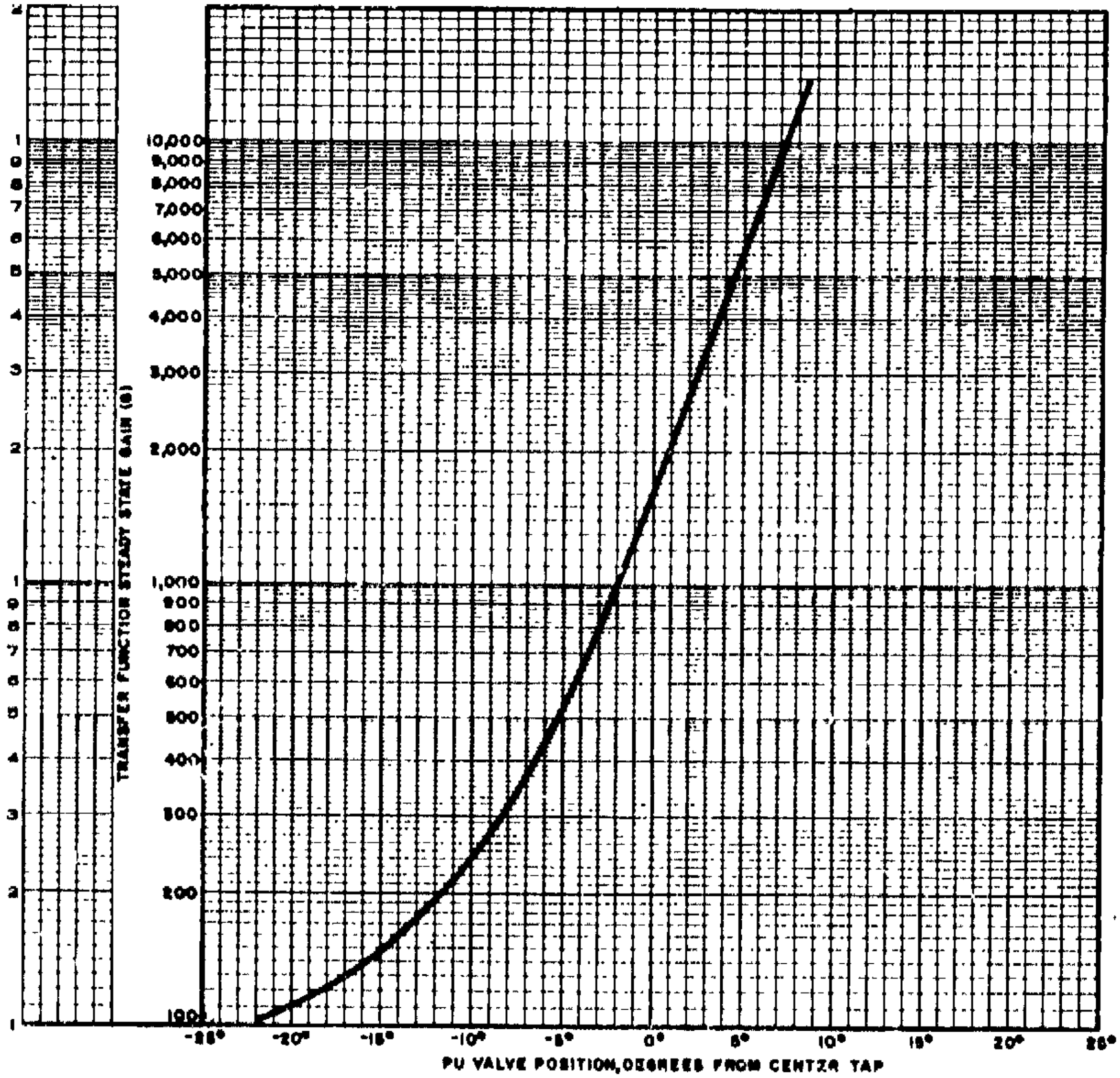


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Figure 8-17. Transfer Function Steady-State Gain Versus PU Valve Position

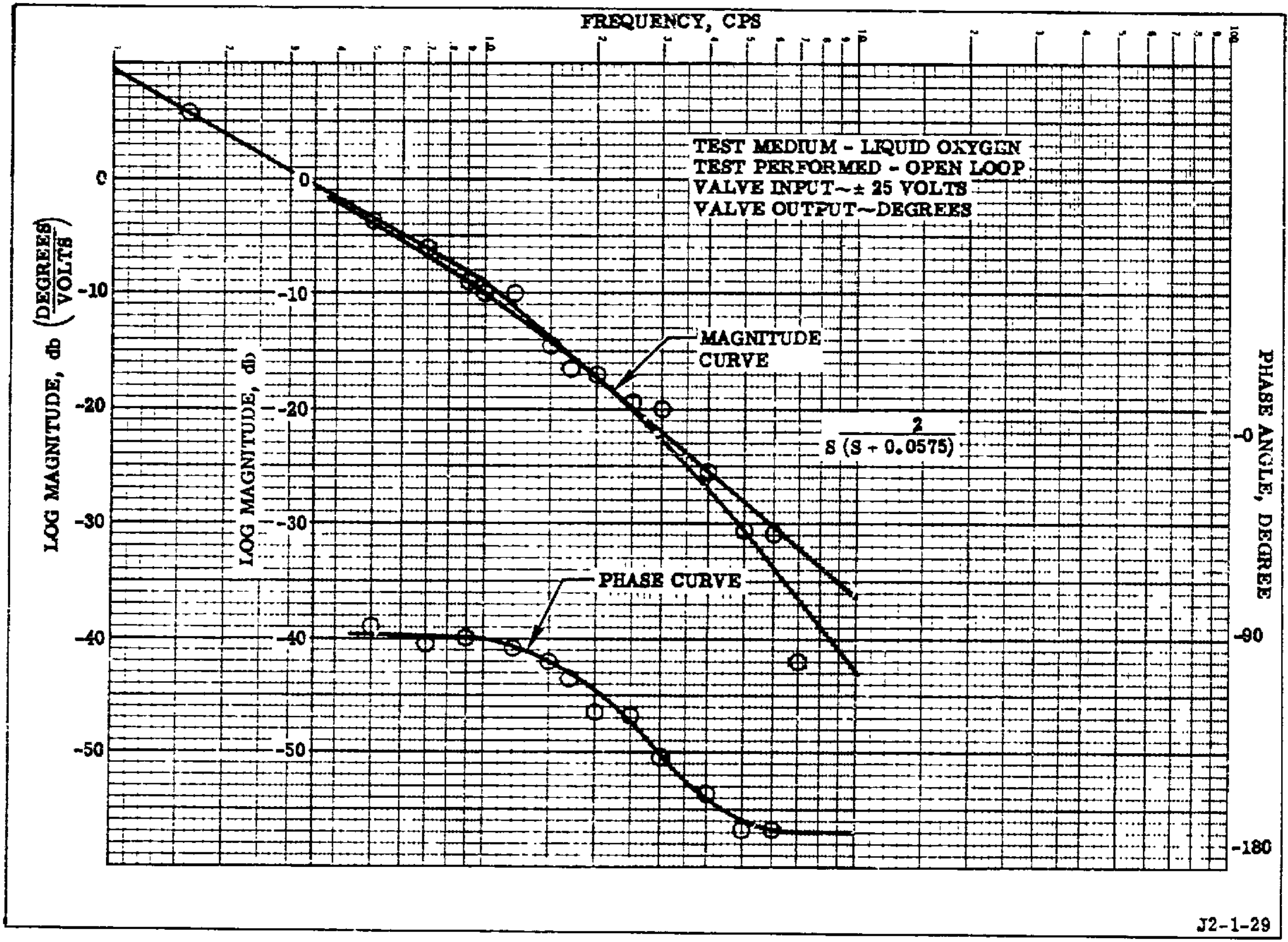

Figure 8-18. Propellant Utilization Valve Motor-Frequency Response

Dependent Variables and Nominal Values				Indepen
A + one percent change of → causes the following percent change in ↓	Fuel Temperature 37. 150° R$^{(a)}$ (Nominal Density = 4.40 lb/cu ft)	Oxidizer Temperature 164. 50° R $^{(a)}$ (Nominal Density = 70. 79 lb/cu ft)	Engine Fuel Inlet Pressure 30. 0 PSIA	Engine Oxidizer Inlet Pressure 39. 0 PSIA
Thrust, 225, 000 lb	-0. 0432	-0. 3201	0. 0035	0. 0277
Specific Impulse, 423. 76 sec	-0. 0123	0. 0249	0. 0019	-0. 0024
Fuel Flowrate, 81. 686 lb/sec	-0. 1321	-0. 1247	0. 0157	0. 0092
Oxidizer Flowrate, 449. 27 lb/sec	-0. 0123	-0. 3849	-0. 0010	0. 0338
Mixture Ratio, 5. 50 O/F	0. 1196	-0. 2602	-0. 0167	0. 0247
GG Fuel Flowrate, 3. 618 lb/sec	-0. 2638	-0. 1492	0. 0168	0. 0124
GG Oxidizer Flowrate, 3. 400 lb/sec	-0. 0025	-0. 3663	0. 0003	0. 0288
Fuel Pump Speed, 26, 709 rpm	0. 1385	-0. 1352	0. 0010	0. 0100
Oxidizer Pump Speed, 8, 571. 7 rpm	-0. 0210	0. 0397	0. 0010	0. 0073
T/C Nozzle Stagration Pressure, 702. 24 psia	-0. 0522	-0. 2986	0. 0048	0. 0256
C* Actual, 7354. 6	-0. 0227	0. 0475	0. 0033	-0. 0045
Fuel Pump Discharge Pressure, 1, 224. 4 psia (total)	-0. 1247	-0. 2887	0. 0161	0. 0234
Oxidizer Pump Discharge Pressure, 1, 080. 8 psia (total)	-0. 0443	-0. 3156	0. 0028	0. 0380
Fuel Turbine Inlet Temperature, 1, 660. 0° R	0. 2539	-0. 2110	-0. 0160	0. 0159
Fuel Turbine Discharge Temperature, 1, 244. 5° R	0. 2528	-0. 2060	-0. 0179	0. 0155
Oxidizer Turbine Inlet Pressure, 85. 687 psia (total)	-0. 0652	-0. 3121	0. 0032	0. 0247
Oxidizer Turbine Discharge Pressure, 32. 024 psia (static)	-0. 0663	-0. 3146	0. 0034	0. 0246
Oxidizer Turbine Discharge Temperature, 1, 071. 6° R	0. 2731	-0. 2248	-0. 0193	0. 0159
Gas Generator Chamber Pressure (injector end), 654. 74 psia	-0. 0686	-0. 3114	0. 0044	0. 0247

(a) At nominal density.

(b) The influence coefficients presented are effective for engines using helium as the oxidizer tank pr

(c) Refer to paragraph 8-24A for information on use of oxidizer tank pressurization flow influence co

Independent Variables and Nominal Values

xidizer perature 50° R [(a)] l Density = lb/cu ft)	Engine Fuel Inlet Pressure 30.0 PSIA	Engine Oxidizer Inlet Pressure 39.0 PSIA	Propellant Utilization Control Setting	C* Correction 1.00	Fuel Tank Pressurization Flowrate 0.8 lb/sec	Oxidizer Tank Pressurization Helium Flowrate 0.145 lb/sec[(b)]	Oxidizer Turbine Accessory Drive BHP 15 HP
3201	0.0035	0.0277	0.00502	0.9443	-0.0023	0.0035	-0.0065
0249	0.0019	-0.0024	-0.00043	1.0135	-0.0011	-0.0003	0.0006
1247	0.0157	0.0092	0.00167	-0.0010	-0.0090	0.0012	-0.0022
3849	-0.0016	0.0338	0.00614	-0.0816	0.0003	0.0042	-0.0080
2602	-0.0167	0.0247	0.00447	-0.0805	0.0093	0.0031	-0.0058
1492	0.0168	0.0124	0.00226	0.3796	-0.0020	0.0016	-0.0029
3663	0.0003	0.0288	0.00523	0.4837	-0.0014	0.0036	-0.0068
1352	0.0010	0.0106	0.00192	0.1699	-0.0005	0.0013	-0.0025
0397	0.0010	0.0073	0.00289	0.2438	-0.0008	0.0028	-0.0053
2986	0.0048	0.0256	0.00465	0.9480	-0.0030	0.0032	-0.0061
0475	0.0033	-0.0045	-0.00082	1.0239	-0.0019	-0.0006	0.0011
2887	0.0161	0.0234	0.00425	0.5706	-0.0026	0.0029	-0.0055
3156	0.0028	0.0380	0.00690	0.6186	-0.0020	0.0048	-0.0090
2110	-0.0160	0.0159	0.00289	0.1012	0.0006	0.0020	-0.0038
2060	-0.0179	0.0155	0.00281	0.0780	0.0007	0.0019	-0.0037
3121	0.0032	0.0247	0.00448	0.4470	-0.0015	0.0031	-0.0058
3146	0.0034	0.0246	0.00439	0.4658	-0.0016	-0.0024	-0.0057
2248	-0.0193	0.0159	0.00275	0.0637	0.0008	0.0014	-0.0034
3114	0.0044	0.0247	0.00448	0.4574	-0.0016	0.0031	-0.0058

sing helium as the oxidizer tank pressurization media (SIVB stage).
k pressurization flow influence coefficients (SII stage).

Figure 8-19. Engine Influence Coefficients (Engines J-2025 Thro

Independent Variables and Nominal Values

Engine xidizer Inlet ressure 39.0 PSIA	Propellant Utilization Control Setting	C* Correction 1.00	Fuel Tank Pressurization Flowrate 0.8 lb/sec	Oxidizer Tank Pressurization Helium Flowrate 0.145 lb/sec(b)	Oxidizer Turbine Accessory Drive BHP 15 HP	Oxidizer Tank Pressurization Correction 1.00(c)
0.0277	0.00502	0.9443	-0.0023	0.0035	-0.0065	-0.3508
-0.0024	-0.00043	1.0135	-0.0011	-0.0003	0.0006	0.0299
0.0092	0.00167	-0.0010	-0.0090	0.0012	-0.0022	-0.1159
0.0338	0.00614	-0.0816	0.0003	0.0042	-0.0080	-0.4287
0.0247	0.00447	-0.0805	0.0093	0.0031	-0.0058	-0.3127
0.0124	0.00226	0.3796	-0.0020	0.0016	-0.0029	-0.1437
0.0288	0.00523	0.4337	-0.0014	0.0036	-0.0068	-0.3676
0.0106	0.00192	0.1699	-0.0005	0.0013	-0.0025	0.1351
0.0073	0.00289	0.2438	-0.0008	0.0028	-0.0053	-0.3561
0.0256	0.00465	0.9480	-0.0030	0.0032	-0.0061	-0.3248
-0.0045	-0.00082	1.0239	-0.0019	-0.0006	0.0011	-0.0574
0.0234	0.00425	0.5706	-0.0026	0.0029	-0.0055	-0.2991
0.0380	0.00690	0.6186	-0.0020	0.0048	-0.0090	-0.4798
0.0159	0.00289	0.1012	0.0006	0.0020	-0.0038	-0.2187
0.0155	0.00281	0.0780	0.0007	0.0019	-0.0037	-0.2109
0.0247	0.00448	0.4470	-0.0015	0.0031	-0.0058	-0.3093
0.0246	0.00439	0.4658	-0.0016	-0.0024	-0.0057	0.7245
0.0159	0.00275	0.0637	0.0008	0.0014	-0.0034	-0.1107
0.0247	0.00448	0.4574	-0.0016	0.0031	-0.0058	-0.3113

tank pressurization media (SIVB stage).

ence coefficients (SII stage).

Figure 8-19. Engine Influence Coefficients (Engines J-2025 Through J-2059)

Dependent Variables and Nominal Values	Indepe			
A + one percent change of → causes the following percent change in ↓	Fuel Temperature 37.161° R(a) (Nominal Density = 4.40 lb/cu ft)	Oxidizer Temperature 164.49° R(a) (Nominal Density = 70.79 lb/cu ft)	Engine Fuel Inlet Pressure 30.0 PSIA	Engine Oxidizer Inlet Pressur 39.0 PSIA
Thrust, 230,000 lb	-0.0444	-0.3193	0.0035	0.0274
Specific Impulse, 425.03 sec	0.0120	0.0245	0.0018	-0.0023
Fuel Flowrate, 83.252 lb/sec	-0.1321	-0.1256	0.0155	0.0096
Oxidizer Flowrate, 457.89 lb/sec	-0.0142	-0.3835	-0.0008	0.0333
Mixture Ratio, 5.50 O/F	0.1179	-0.2578	-0.0164	0.0237
GG Fuel Flowrate, 3.712 lb/sec	-0.2659	-0.1476	0.0169	0.0123
GG Oxidizer Flowrate, 3.489 lb/sec	-0.0025	-0.3662	0.0002	0.0293
Fuel Pump Speed, 27,272 rpm	0.1384	-0.1351	0.0009	0.0108
Oxidizer Pump Speed, 8,687.3 rpm	-0.0219	0.0406	0.0010	0.0074
T/C Nozzle Stagnation Pressure, 718.05 psia	-0.0532	-0.2981	0.0048	0.0254
C* Actual, 7378.0	-0.0223	0.0470	0.0032	-0.0044
Fuel Pump Discharge Pressure, 1,247.3 psia (total)	-0.1249	-0.2876	0.0156	0.0235
Oxidizer Pump Discharge Pressure, 1,106.6 psia (total)	-0.0459	-0.3144	0.0029	0.0376
Fuel Turbine Inlet Temperature, 1,660.0° R	0.2560	-0.2124	-0.0162	0.0164
Fuel Turbine Discharge Temperature, 1,234.8° R	0.2550	-0.2075	-0.0181	0.0160
Oxidizer Turbine Inlet Pressure, 90.004 psia (total)	-0.0676	-0.3100	0.0033	0.0249
Oxidizer Turbine Discharge Pressure, 33.706 psia (static)	-0.0689	-0.3128	0.0035	0.0247
Oxidizer Turbine Discharge Temperature, 1,075.5° R	0.2715	-0.2233	-0.0192	0.0162
Gas Generator Chamber Pressure (injector end), 696.91 psia	-0.0692	-0.3108	0.0044	0.0250

(a) At nominal density.

(b) The influence coefficients presented are effective for engines using helium as the oxidizer tank pr

(c) Refer to paragraph 8-24A for information on use of oxidizer tank pressurization flow influence co

Figure 8-20. Engine Influence Coefficients (Engines J-2060 and Subsequent)

er ture R(a) ensity = cu ft)	Engine Fuel Inlet Pressure 30.0 PSIA	Engine Oxidizer Inlet Pressure 39.0 PSIA	Propellant Utilization Control Setting	C* Correction 1.00	Fuel Tank Pressurization Flowrate 0.90 lb/sec	Oxidizer Tank Pressurization Helium Flowrate 0.144 lb/sec(b)	Oxidizer Turbine Accessory Drive BHP 15 HP	Oxid Pres Co
	Independent Variables and Nominal Values							
3	0.0035	0.0274	0.00493	0.9447	-0.0025	0.0034	-0.0064	-0.
5	0.0018	-0.0023	-0.00041	1.0128	-0.0012	-0.0003	0.0005	0.
6	0.0155	0.0096	0.00172	-0.0040	-0.0098	0.0012	-0.0022	-0.
5	-0.0008	0.0333	0.00600	-0.0797	0.0003	0.0041	-0.0077	-0.
8	-0.0164	0.0237	0.00428	-0.0758	0.0101	0.0030	-0.0055	-0.
6	0.0169	0.0123	0.00223	0.3873	-0.0024	0.0015	-0.0029	-0.
2	0.0002	0.0293	0.00527	0.4808	-0.0015	0.0036	-0.0068	-0.
1	0.0009	0.0108	0.00194	0.1690	-0.0005	0.0013	-0.0025	-0.
6	0.0010	0.0074	0.00281	0.2425	-0.0008	0.0028	-0.0052	-0.
1	0.0048	0.0254	0.00458	0.9479	-0.0033	0.0032	-0.0059	-0.
0	0.0032	-0.0044	-0.00078	1.0228	-0.0021	-0.0005	0.0010	0.0
6	0.0156	0.0235	0.00424	0.5708	-0.0030	0.0029	-0.0055	-0.3
4	0.0029	0.0376	0.00677	0.6186	-0.0022	0.0047	-0.0087	-0.
4	-0.0162	0.0164	0.00296	0.0908	0.0008	0.0020	-0.0038	-0.2
5	-0.0181	0.0160	0.00289	0.0664	0.0010	0.0020	-0.0037	-0.2
0	0.0033	0.0249	0.00449	0.4455	-0.0017	0.0031	-0.0058	-0.3
3	0.0035	0.0247	0.00440	0.4630	-0.0017	-0.0023	-0.0056	0.7
3	-0.0192	0.0162	0.00278	0.0492	0.0011	0.0014	-0.0034	-0.1
3	0.0044	0.0250	0.00450	0.4571	-0.0018	0.0031	-0.0058	-0.3

helium as the oxidizer tank pressurization media (SIVB stage).
ressurization flow influence coefficients (SII stage).

---

sequent)

Independent Variables and Nominal Values

Engine Oxidizer Inlet Pressure 39.0 PSIA	Propellant Utilization Control Setting	C* Correction 1.00	Fuel Tank Pressurization Flowrate 0.90 lb/sec	Oxidizer Tank Pressurization Helium Flowrate 0.144 lb/sec(b)	Oxidizer Turbine Accessory Drive BHP 15 HP	Oxidizer Tank Pressurization Correction 1.00(c)
0.0274	0.00493	0.9447	-0.0025	0.0034	-0.0064	-0.3543
-0.0023	-0.00041	1.0128	-0.0012	-0.0003	0.0005	0.0292
0.0096	0.00172	-0.0040	-0.0098	0.0012	-0.0022	-0.1237
0.0333	0.00600	-0.0797	0.0003	0.0041	-0.0077	-0.4307
0.0237	0.00428	-0.0758	0.0101	0.0030	-0.0055	-0.3091
0.0123	0.00223	0.3873	-0.0024	0.0015	-0.0029	-0.1428
0.0293	0.00527	0.4808	-0.0015	0.0036	-0.0068	-0.3811
0.0108	0.00194	0.1690	-0.0005	0.0013	-0.0025	-0.1401
0.0074	0.00281	0.2425	-0.0008	0.0028	-0.0052	-0.3708
0.0254	0.00458	0.9479	-0.0033	0.0032	-0.0059	-0.3291
-0.0044	-0.00078	1.0228	-0.0021	-0.0005	0.0010	0.0561
0.0235	0.00424	0.5708	-0.0030	0.0029	-0.0055	-0.3062
0.0376	0.00677	0.6186	-0.0022	0.0047	-0.0087	-0.4835
0.0164	0.00296	0.0908	0.0008	0.0020	-0.0038	-0.2319
0.0160	0.00289	0.0664	0.0010	0.0020	-0.0037	-0.2227
0.0249	0.00449	0.4455	-0.0017	0.0031	-0.0058	-0.3178
0.0247	0.00440	0.4630	-0.0017	-0.0023	-0.0056	0.7773
0.0162	0.00278	0.0492	0.0011	0.0014	-0.0034	-0.1079
0.0250	0.00450	0.4571	-0.0018	0.0031	-0.0058	-0.3216

zer tank pressurization media (SIVB stage).
nfluence coefficients (SII stage).

c. Engine fuel inlet pressure: 29.5 psia.

d. Engine oxidizer inlet pressure: 42 psia.

e. Propellant utilization setting required for -8.0 percent mixture-ratio shift.

8-20. Because the influence coefficients are linear, the total effects of several influences acting simultaneously on an engine can be determined by adding the individual effects of each influence.

$$\frac{F_E - F_{E_N}}{F_{E_N}} = \frac{T_F - T_{F_N}}{T_{F_N}} F_{T_F} + \frac{T_O - T_{O_N}}{T_{O_N}} F_{T_O} + \frac{P_F - P_{F_N}}{P_{F_N}} F_{P_F}$$

$$+ \frac{P_O - P_{O_N}}{P_{O_N}} F_{P_O} + \frac{PU - PU_N}{PU_N} F_{PU}$$

NOTE

F_E, T_F, T_O, P_F, P_O, and PU are the actual Engine Log Book values of engine thrust, fuel temperature, oxidizer temperature, fuel pump inlet pressure, oxidizer pump inlet pressure, and propellant utilization control setting, respectively.

- F_{E_N}, T_{F_N}, T_{O_N}, P_{F_N}, P_{O_N}, and PU_N are the nominal values of these parameters, as listed in figures 8-19 and 8-20.
- F_{T_F}, F_{T_O}, F_{P_F}, F_{P_O}, and F_{PU} are the influence coefficients for engine thrust found in the appropriate columns of figures 8-19 and 8-20.

8-21. The calculation for the example would be as follows: The percentage change in propellant utilization (PU) control setting to give a specified change in mixture ratio is found from the equation:

$$\frac{MR_E - MR_{E_N}}{MR_{E_N}} = \frac{PU - PU_N}{PU_N} MR_{PU}$$

where MR_{PU} is the influence coefficient for engine mixture ratio found in the PU control setting column: A -8.0 percent change in MR_{E_N} means

$$\frac{MR_E - MR_{E_N}}{MR_{E_N}} = 0.08$$

Therefore, using coefficients of figure 8-19:

$$\frac{PU - PU_N}{PU} = \frac{-0.08}{MR_{PU}} = \frac{-0.08}{0.00447} = -17.897 = -1789.7 \text{ percent change in engine PU control setting}$$

Substituting appropriate values gives:

$$\frac{F_E - 225,000}{225,000} = \frac{38 - 37.15}{37.15}(-0.0432) + \frac{165 - 164.5}{164.5}(-0.3201)$$

$$+ \frac{29.5 - 30.0}{30.0}(0.0035) + \frac{42.0 - 39.0}{39.0}(0.0277) + (-17.897)(0.00502)$$

$$= -0.090736 = -9.0736 \text{ percent}$$

Therefore:

$$F_E = (225,000)(-0.090736) + 225,000 = 204,584 \text{ pounds}$$

The incremental thrust change is found to be -20,416 pounds for the conditions stated, yielding a final engine thrust of 204,584 pounds.

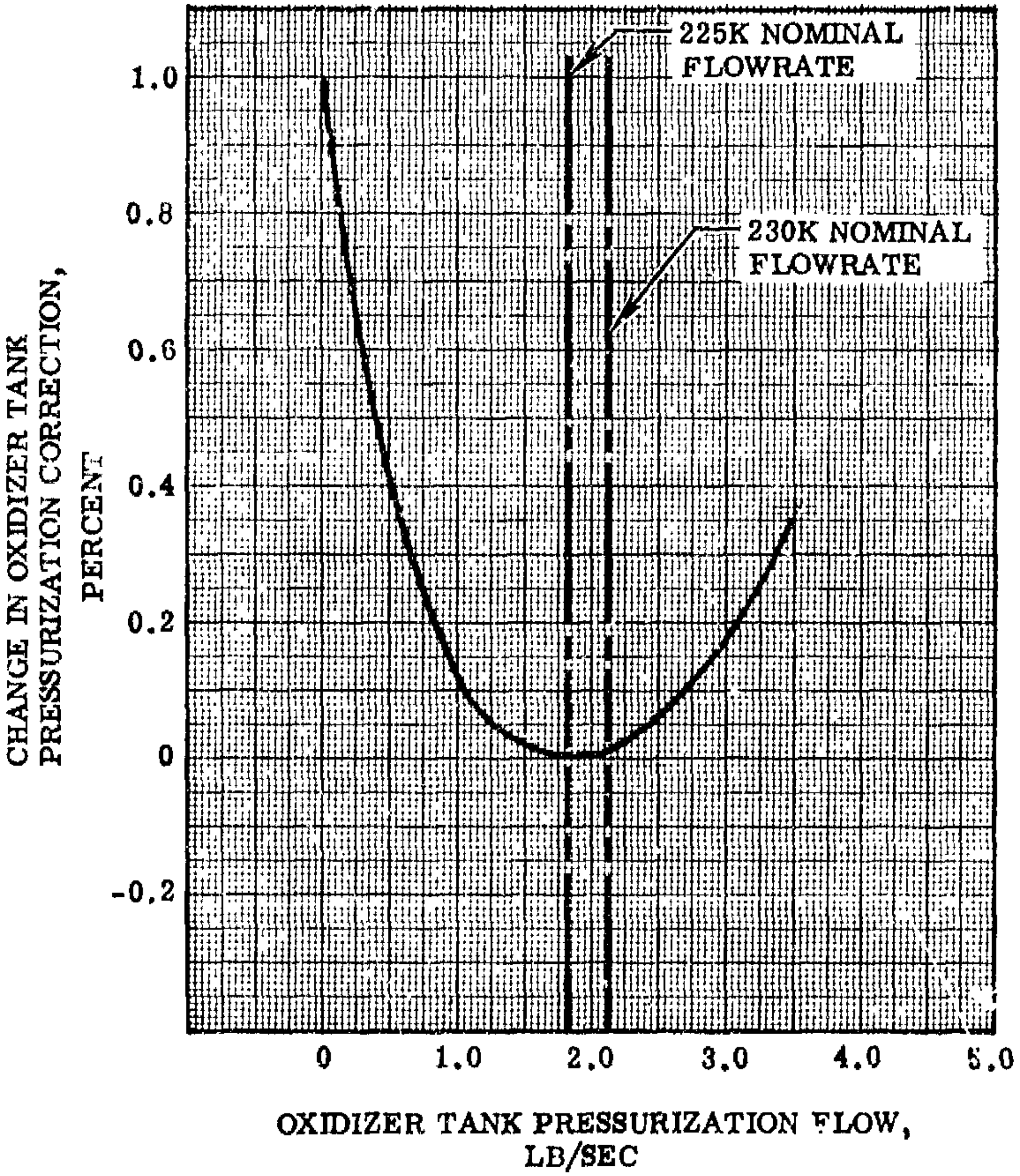

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Figure 8-21. Nonlinear Correction Curve for Oxidizer Tank Pressurization Flow (Oxygen)

8-22. NONLINEAR CORRECTIONS.

8-23. A special computational procedure has been devised to extend the usefulness of engine influence coefficients. This technique is used to allow nonlinear corrections to be made for certain parameters where the linear approximation is not sufficiently accurate. *An example of this method is the c* correction. In* this case, a plot of c* correction versus the change in engine mixture ratio is included with the table of *influence coefficients. (See figure 8-25.)*

8-24. The change in engine mixture ratio is computed for the changes in propellant densities and turbopump inlet pressure, and with the assumption that the c* correction is zero. With this change in engine mixture ratio, the c* correction is read from the curve. This value of c* correction is used with the other independent variables to compute the changes in the remaining dependent variables. For example, the change in engine mixture ratio used to effect the percent thrust change in the preceding example was -8.00 percent; the c* correction from figure 8-25 is -0.075 percent. The true change in engine thrust is therefore:

$$(\text{percent change in } F_E) = -9.0736 - 0.075\ (0.9443)$$

$$= -9.0736 - 0.070822 = 9.1444 \text{ percent}$$

Similarly, other nonlinear corrections would be applied as additional terms in the summation of effects in a like procedure.

8-24A. OXIDIZER TANK PRESSURIZATION FLOW (OXYGEN) NONLINEAR CORRECTIONS.

8-24B. Engine performance changes with respect to oxidizer tank pressurization flow are nonlinear. *Therefore, a nonlinear correction technique must be used.* This technique uses the oxidizer tank perssurization correction influence coefficent column (figures 8-19 and 8-20) together with the nonlinear correction curve of figure 8-21. For any given oxidizer tank pressurization flowrate, obtain a value for change in the oxidizer tank pressurization influence coefficients (see figure 8-19 for 225K engines and figure 8-20 for 230K engines) to find the effect on the dependent variables. For example, to find the effect on thrust (225K engine) of an increase in oxidizer tank pressurization from the nominal of 1.8 lb/sec to 3.5 lb/sec, a pressurization correction change of 0.35 percent is read from figure 8-21. The change in thrust is then:

$$\text{Percent change in thrust} = 0.35\ (-0.3508) = 0.123 \text{ percent}$$

$$\text{Change in thrust} = \frac{-0.123}{100}\ (225,000) = -277 \text{ pounds}$$

Figures 8-22 through 8-24 deleted.

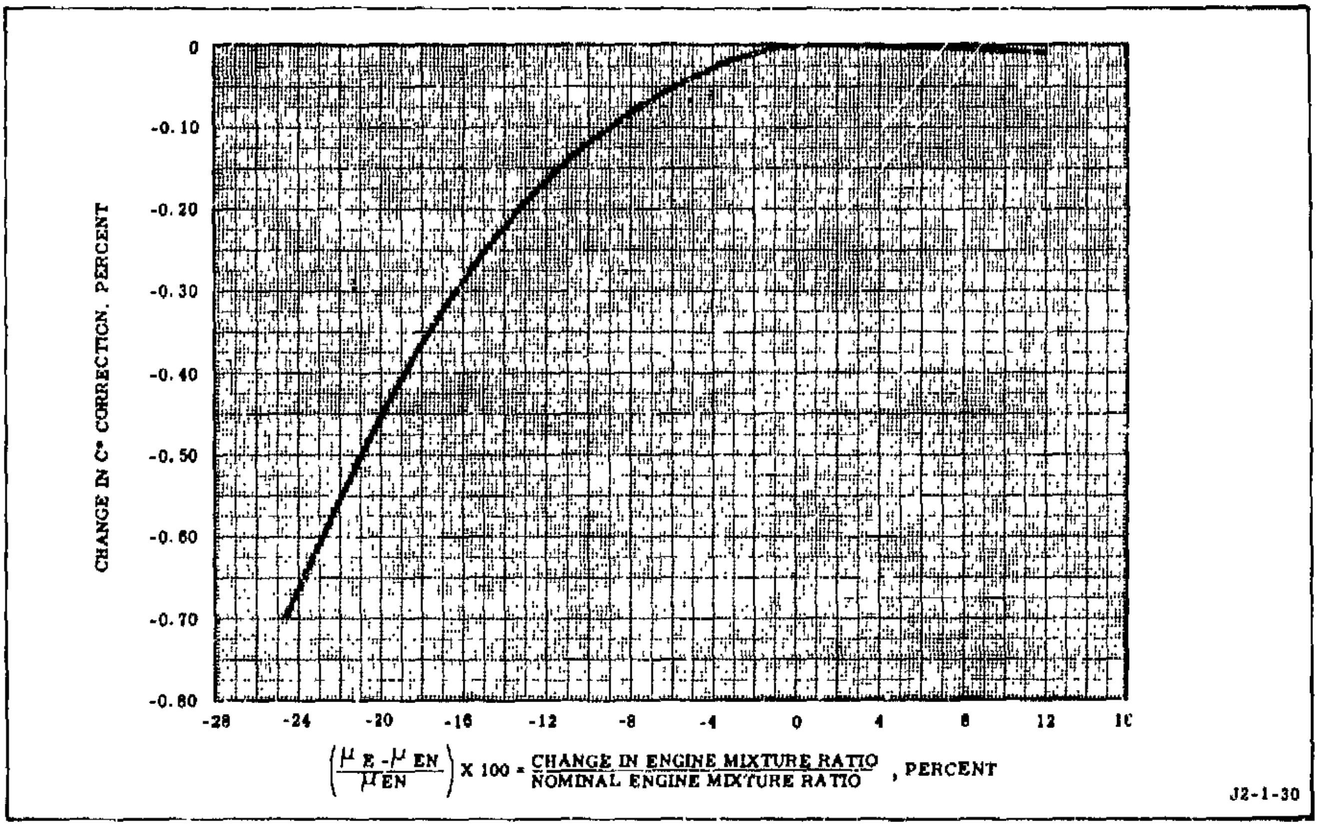


Figure 8-25. C* Correction Curve

8-25. PROPELLANT SYSTEM PRESSURE REQUIREMENTS.

8-26. A Summation of the effects including all known variables on engine NPSH for full PU excursion conditions is presented in figures 8-27 and 8-29. The pressure drop between the engine inlet and the pump inlet is 0.6 psi at a flowrate of 84.1 lb/sec for the fuel inlet duct in the neutral position and 1.1 psi at a flowrate of 460 lb/sec for the oxidizer inlet duct in the neutral position.

Figure 8-26. (Deleted)

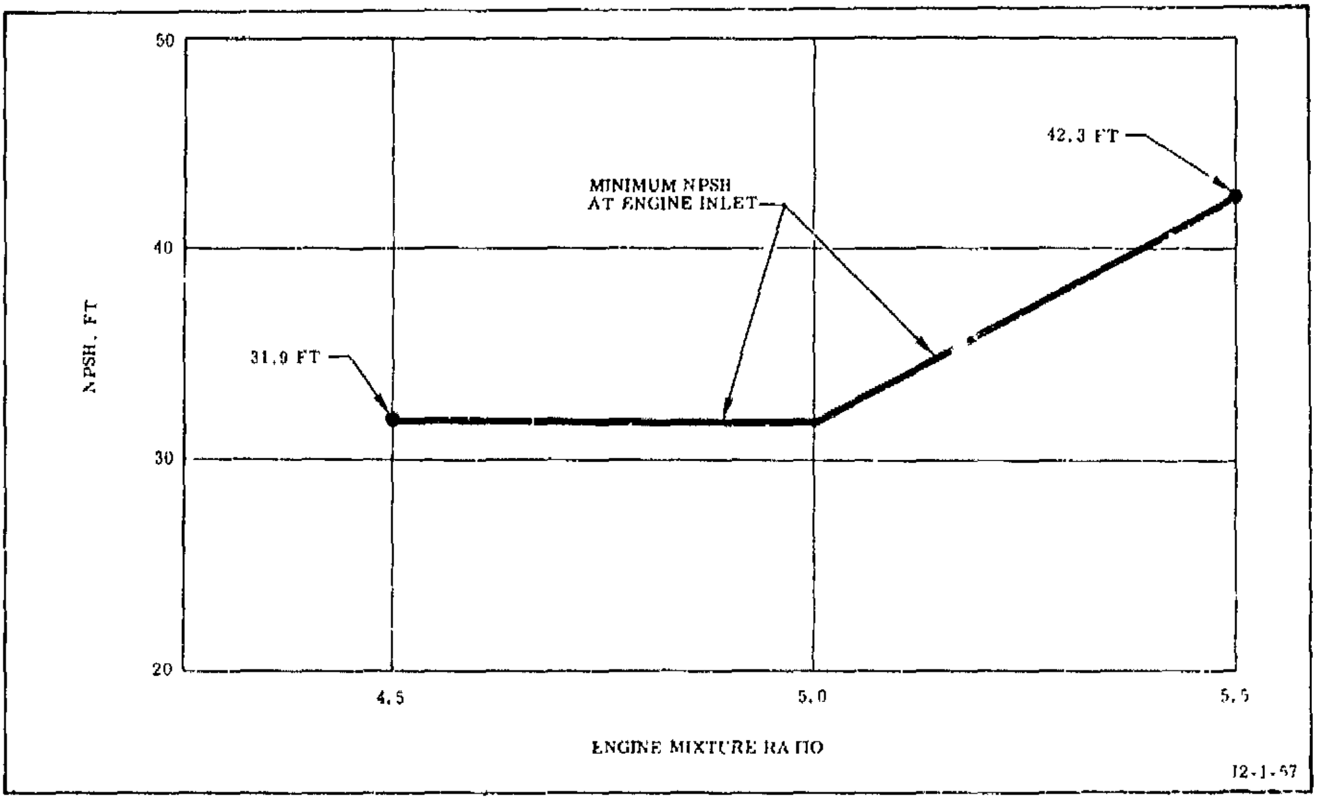


Figure 8-27. Mainstage Oxidizer NPSH Requirements Versus Engine Mixture Ratio

All data on pages 8-31 and 8-32 deleted.

Figure 8-28. (Deleted)

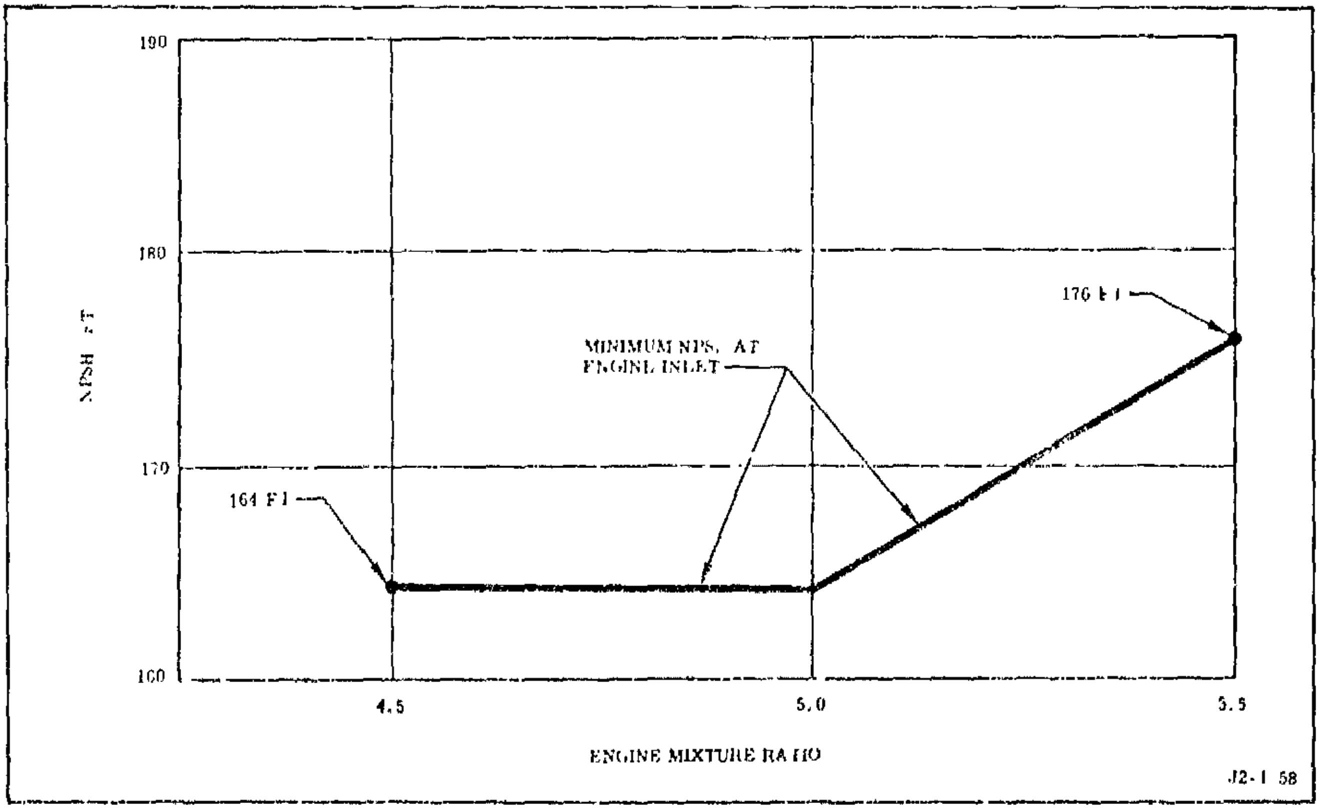


Figure 8-29. Mainstage Fuel NPSH Requirements Versus Engine Mixture Ratio

8-27. PROPELLANT BLEED FLOW DURING ENGINE CONDITIONING.

8-28. To ensure proper operation of the engine turbopumps during the start transient, engine chilldown must provide turbopump inlet conditions that will ensure sufficient NPSH values. Chilldown is obtained by facility recirculating pumps which extract flow through the engine propellant bleed lines. Liquid propellants should be present throughout the feed system to facilitate the pumping, while ensuring sufficiently subcooled liquid at the turbopumps to provide the required pre-start NPSH values. Curves of figure 8-30 outline pre-start bleed flowrates as a function of the pressure drop across the engine bleed system for average bleed flows, and corresponding pressure drops for both liquid hydrogen and liquid oxygen. Curves of figure 8-30 may be used to control or measure the engine bleed system flowrate using engine pressure drops.

8-29. SURGE AND TURBOPUMP INLET PRESSURE. The engine inlet ducting, turbopump inlet casing, and turbopump mounting structure are designed to withstand surge pressures of 93 psi above the nominal inlet pressure in the oxidizer system and 102 psi in the fuel system. In terms of total pressure (surge plus nominal operating), the limitations are 132 psia for the fuel inlet system and 132 psia for the oxidizer inlet system. It is necessary, therefore, in every specific application of the engine, that an evaluation of possible vehicle-ducting configurations be made in terms of elevation from engine connect point to propellant tank discharge and of ducting-run length and diameter.

8-30. Rocketdyne has developed a digital computer program for analyzing water-hammer effects based on a solution of the one-dimensional wave equation. This program has had significant success in predicting pressure surging caused by rapid valve closure in series piping systems. The input data for this program is diameter, run length, wall thickness, modulus of elasticity, Poisson's ratio for the ducting, free acoustic velocity, adiabatic bulk modulus, flowrate of the propellant, and the propellant valve closing characteristic. Any questions concerning proposed vehicle ducting layouts, in regard to pressure surges, should be referred to Rocketdyne and be accompanied by the required data.

8-31. To minimize cutoff impulse and maintain the specified close tolerances on cutoff impulse variation, the engine employs rapid main propellant valve closures; this results in water-hammer pressure surges. The system surge pressures have been evaluated for the most rapid closures anticipated under propellant flow and pressure conditions encountered at the maximum of mixture ratio control.

8-32. The maximum run lengths of propellant feed ducting, which generates surges safely below the maximum surge levels at nominal inlet pressure conditions, are 29.0 feet for the fuel system and 6.0 feet for the oxidizer system at the engine inlet flange. The maximum run lengths are based on the use of 7.9-inch-ID, low-pressure, stainless-steel piping. The utilization of larger diameter ducting will reduce the surge pressure as a result of decreasing the flow velocity; however, the relation is not direct. If structural requirements of proposed vehicles dictate run lengths greater than those mentioned, the investigation of surge-suppressing methods is recommended.

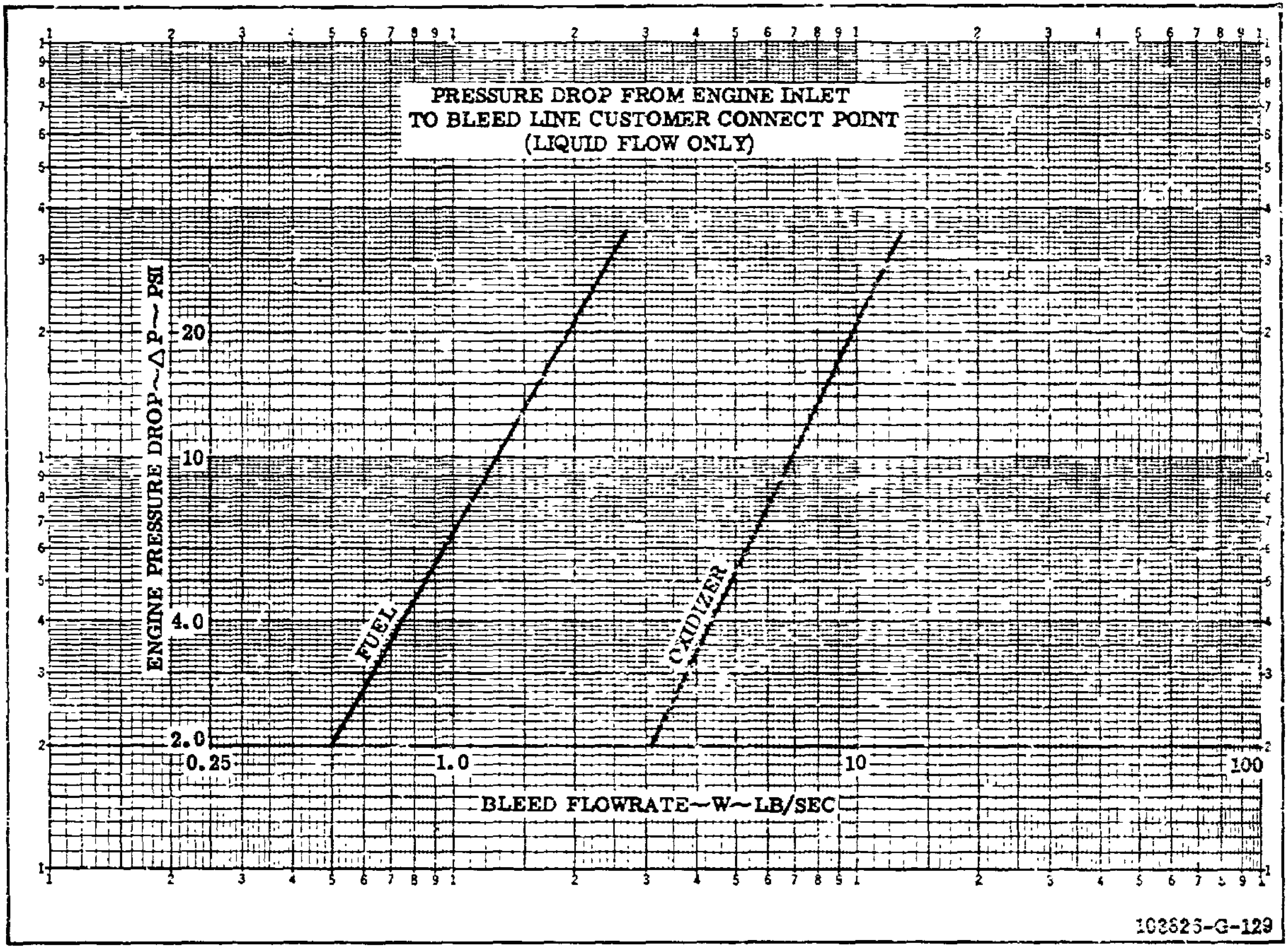


Figure 8-30. Propellant Bleed Flow During Engine Conditioning

8-33. PROPELLANT SYSTEM PRE-VALVE DATA.

8-34. The engine was designed on the assumption that the main propellant valves are the only valves in the vehicle propellant feed systems. Additional feed system valves, called pre-valves, would only be added to fulfill vehicle requirements, independently of the engine. If pre-valves are added, and if their cycle of operation is arranged so that both the pre-valve and the engine valve could be closed simultaneously, trapping liquid cryogenic propellant, the vehicle manufacturer must then provide for pressure relief on the volume between the valves. Pressure would increase due to propellant thermal expansion, and flexible duct contraction if the engine is gimbaled while in this condition. Total pressure limitation is presented in the previous paragraphs on surge and turbopump inlet pressure. The thermal expansion which occurs will effect an engine fuel volume of 1.5 cu ft and an oxidizer volume of 1.48 cu ft. Engine gimbaling at the specified rate, with a liquid-filled duct, will require a relief capacity of 2.9 gps. The vehicle contractor should coordinate with Rocketdyne prior to determining the pre-valve closing sequence. Proper sequencing of the valves is important to ensure a safe engine shutdown.

8-35. OXIDIZER TANK PRESSURIZATION SYSTEM DATA.

8-36. The pressurant for vehicle oxidizer tank pressurization is obtained from a heat exchanger located in the oxidizer turbopump turbine exhaust duct. The pressurant may be either engine-supplied oxygen or, on engines incorporating MD105 or MD194 change, vehicle-supplied helium.

8-37. Variation of pressurization system flowrates alter the engine operating level. The changes in engine performance due to independently varying the tank pressurization flowrates may be calculated using the information in paragraph 8-24A.

8-38. The four-coil heat exchanger design provides for increased flexibility in vehicle tank pressurization demands. Refer to R-3825-1B for calculated performance curves for oxygen one-coil operation and helium two-coil operation.

NOTE

The customer connect pressure includes pressure drops through all interconnect lines and orifices.

- The helium loss and heat transfer were based on inlet conditions of 400 ±30 psia and 50° (+20°, -0°)R, except as noted.
- Heat exchanger data is based on component and engine testing; engine operating levels are based on calculated values.
- The curves show the operating condition for an engine with maximum, null, and minimum settings of the propellant utilization valve.

8-39. To compute the vehicle tanking mixture ratio, the tank pressurization flow requirements should be added to the engine propellant consumption, since engine mixture ratio and specific impulse do not include pressurization flowrates.

8-40. FUEL TANK PRESSURIZATION SYSTEM DATA.

8-41. Pressure for pressurizing the vehicle fuel tank is obtained by bleeding gaseous hydrogen from the engine thrust chamber fuel injection manifold.

8-42. Variation of pressurization system flowrates alters the engine operating level. Changes in engine performance due to independently varying the tank pressurization flowrates may be calculated using the influence coefficients in figures 8-19 and 8-20.

8-43. Variation in fuel tank pressurant flowrates resulting from vehicle system demands and engine operating conditions produces changes in customer connection conditions. Refer to R-3825-1B for curves on fuel tank pressurization pressures versus flowrate and fuel tank pressurization temperature versus flowrate.

8-44. If tank pressurization flowrates, other than the nominal specified, are required for a particular application, the anticipated flows should be referred to Rocketdyne for consideration. A recalibration of the engine may be necessary to accommodate the new requirements.

8-45. ENGINE INTEGRAL HYDROGEN-HELIUM START TANK ENERGY LEVELS.

8-46. Helium stored under pressure in the helium tank is used to supply pneumatic pressure to the engine control system. Gaseous hydrogen stored under pressure in the hydrogen start tank is used as the energy source for starting the engine. Both the helium tank and the hydrogen start tank are filled from a ground source. On restart-mission engines, the hydrogen start tank is refilled during the preceding engine operation. Refer to R-3825-1B for prelaunch conditions required to provide satisfactory engine restart in flight.

Figures 8-30A through 8-39 deleted.

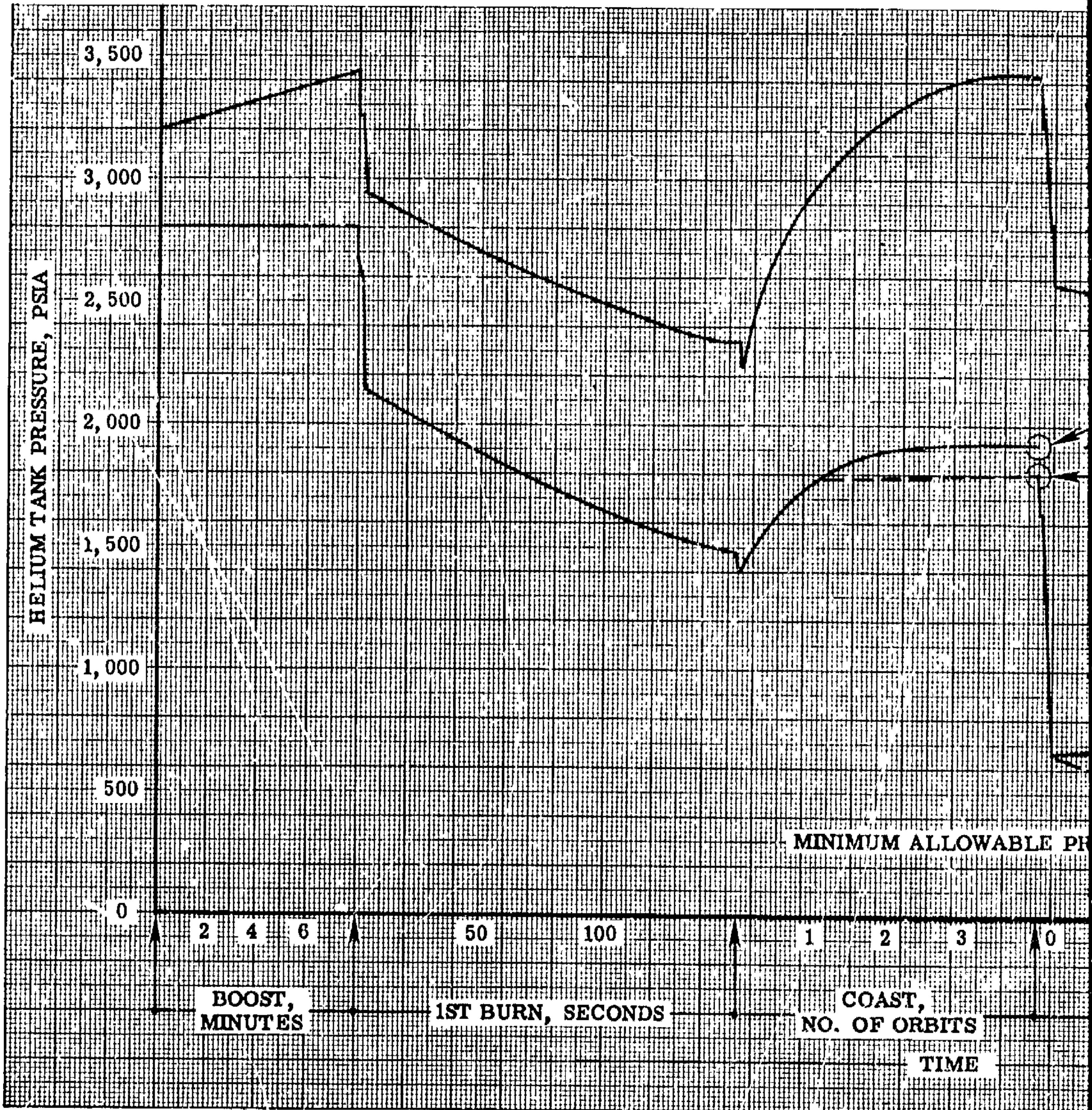
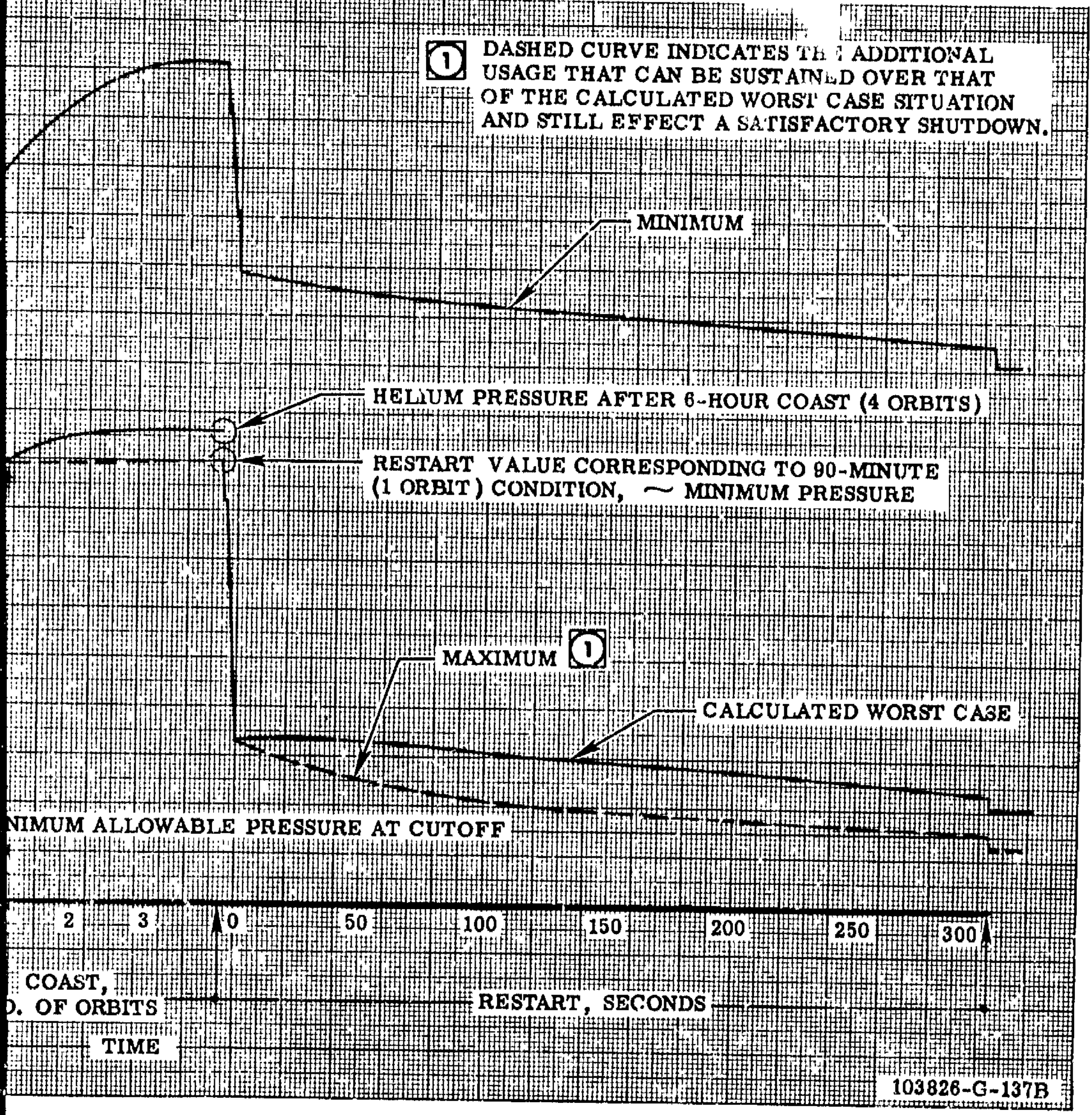


Figure 8-40. Engine Helium Consumption (SV Vehicle, SIVB Stage)

Pages 8-39 through 8-50B deleted.



① DASHED CURVE INDICATES THE ADDITIONAL USAGE THAT CAN BE SUSTAINED OVER THAT OF THE CALCULATED WORST CASE SITUATION AND STILL EFFECT A SATISFACTORY SHUTDOWN.
MINIMUM
HELIUM PRESSURE AFTER 6-HOUR COAST (4 ORBITS)
RESTART VALUE CORRESPONDING TO 90-MINUTE (1 ORBIT) CONDITION, ~ MINIMUM PRESSURE
MAXIMUM ①
CALCULATED WORST CASE
NIMUM ALLOWABLE PRESSURE AT CUTOFF
2
3
0
50
100
150
200
250
300
COAST,
D. OF ORBITS
RESTART, SECONDS
TIME
103826-G-137B

8-47. Engine helium consumption which can be expected during an SV-SIVB restart mission is shown in figure 8-40.

8-48. ENGINE CHARACTERISTICS.

8-49. TRANSIENT CHARACTERISTICS. Maximum and minimum variations of the fundamental engine parameters during start, utilizing a pre-chilled thrust chamber, are shown in figures 8-41 through 8-45. Characteristics for both altitude and sea-level conditions are represented.

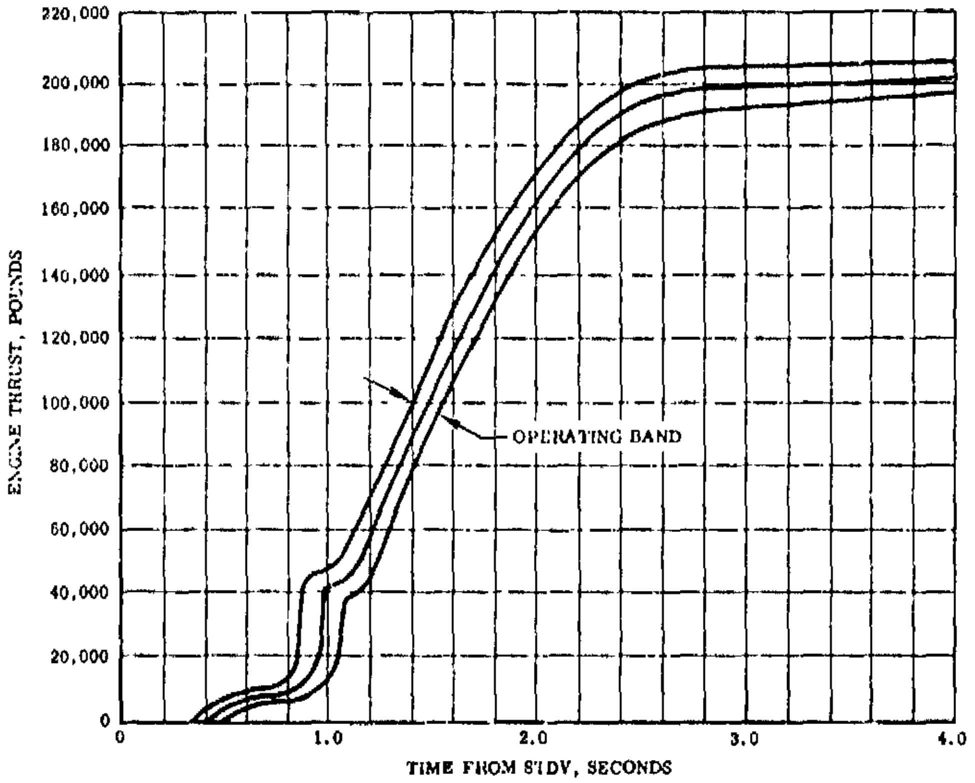


Figure 8-41. Thrust Increase at Altitude With PU Valve in Null Position

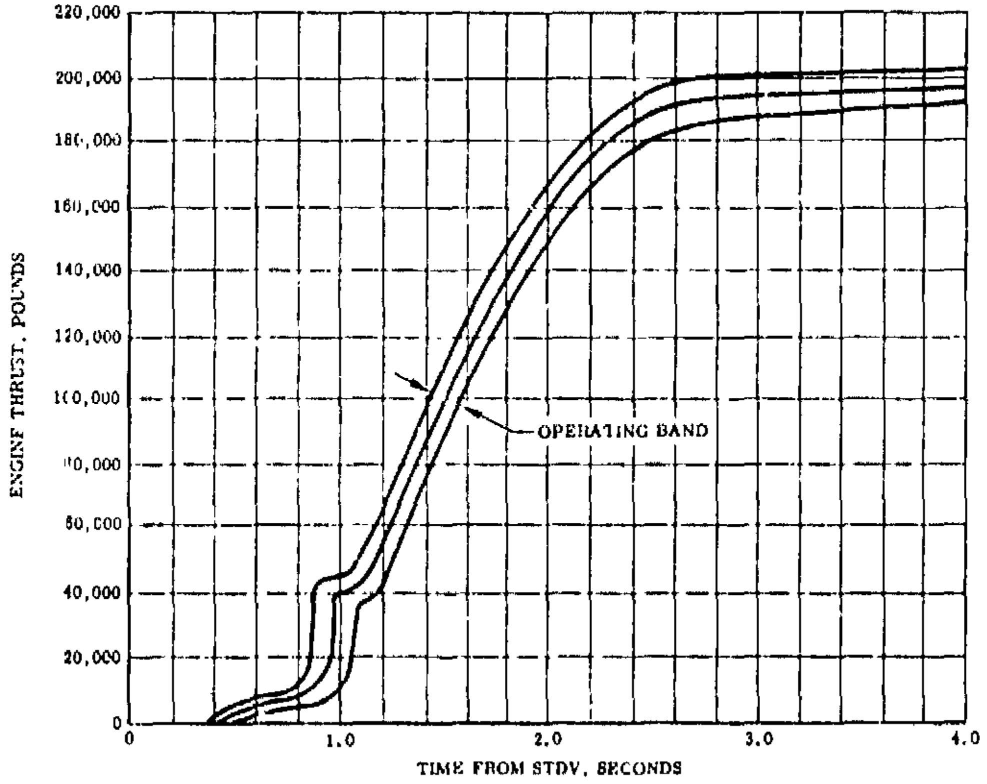


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Figure 8-41A. Thrust Increase at Altitude With Mixture Ratio Control Valve in 4.8 Engine Mixture Ratio Position (Mixture Ratio Control Valve Open on SII Stage or SIVB 200-Series Stage)

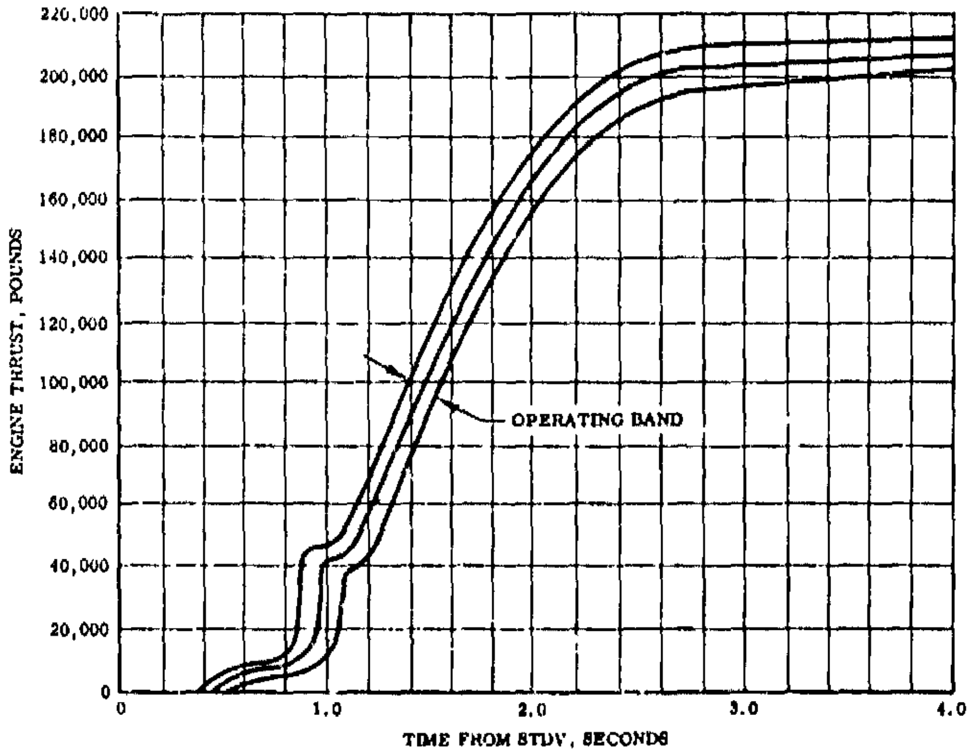

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Figure 8-41B. Thrust Increase at Altitude With Mixture Ratio Control Valve in 5.0 Engine Mixture Ratio Position (Mixture Ratio Control Valve Closed on SIVB 500-Series Stage)

8-50. The minimum and maximum conditions presented in the figures represent 3 deviations due to changes in significant variables. The propellant utilization valve was considered to be locked in position for nominal bypass flow.

8-51. Propellant consumption during start may be determined from figures 8-42 and 8-43.

8-52. In-Test Mixture Ratio and Fuel Pump Speed Trends. In-test mixture ratio data and fuel pump speed characteristics are shown in figures 8-46 and 8-47. The repeatability bands represent maximum data scatter bands at the slice times, studied with a best-fit line constructed between slices.

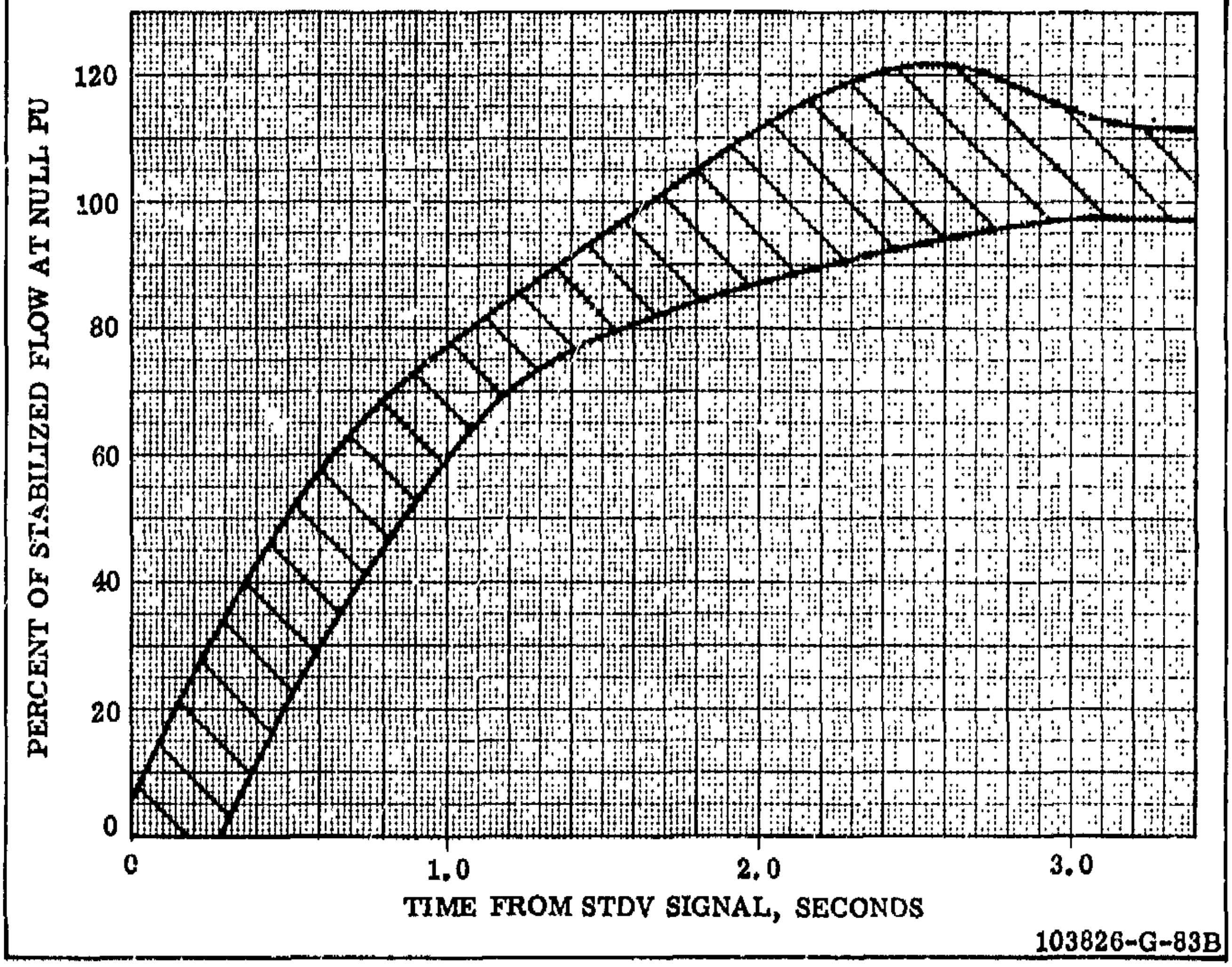

Figure 8-42. Fuel Flowrate Increase (Engines J-2025 Through J-2059)

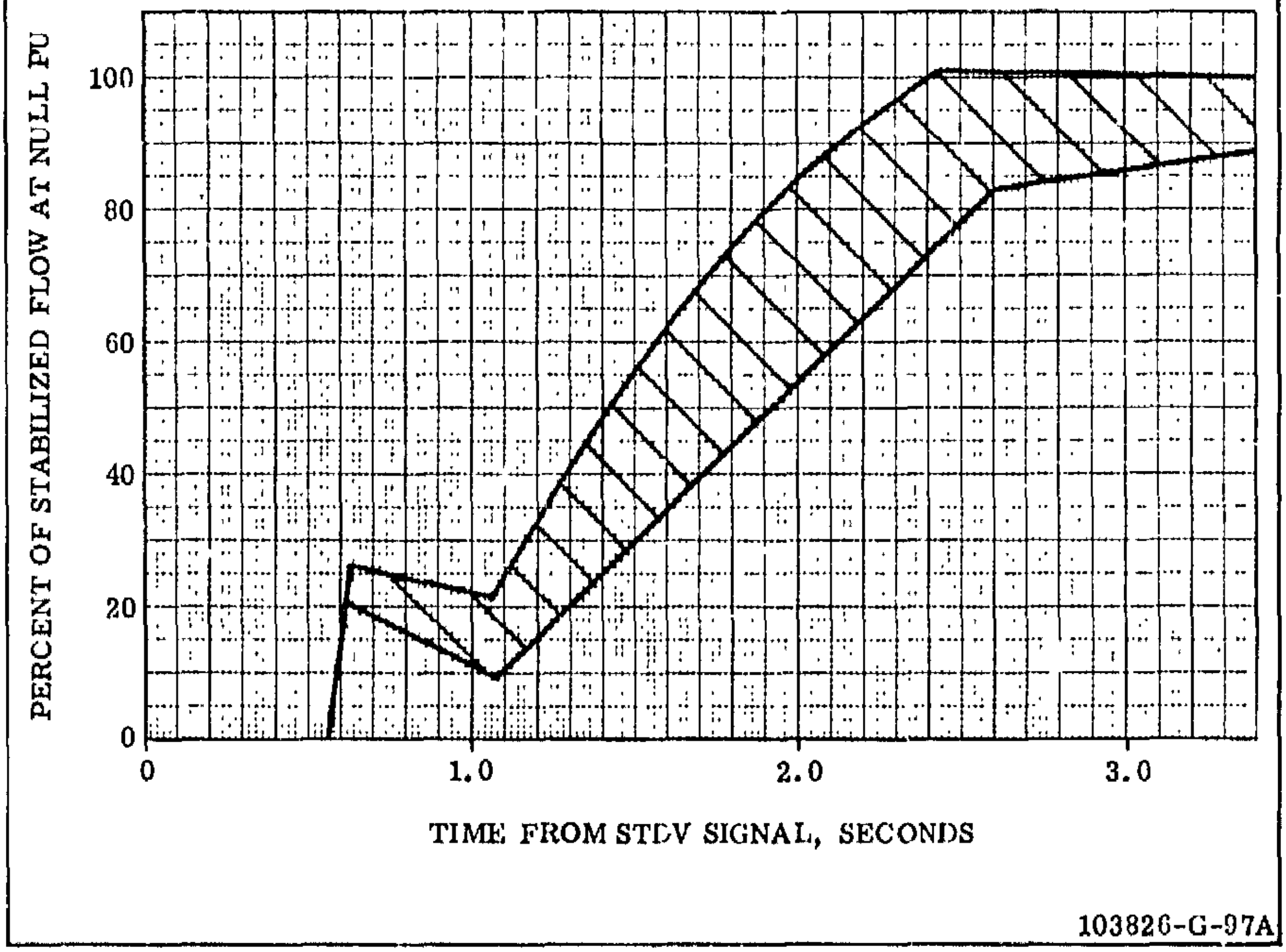

Figure 8-43. Oxidizer Flowrate Increase (Engines J-2025 Through J-2059)

8-53. CUTOFF IMPULSE. Thrust decrease, measured from engine cutoff signal to 5 percent of rated thrust, is shown in figures 8-48 through 8-51. A summary of cutoff impulse characteristics is presented in figure 8-52. Means, run-to-run standard deviations, and overall standard deviations are tabulated for cutoff impulse; means and overal standard deviations are tabulated for the time for thrust to reach 5 percent of its rated value. Cutoff impulse values in figure 8-52 are from cutoff signal to 5 percent of rated thrust. To obtain the impulse to zero thrust, add 6,400 pound-seconds to these values. Notable changes responsible for cutoff impulse variations are as follows:

a. On engines incorporating MD154 change or engines that have fast-shutdown (pressure-actuated shutoff) valve 557817 installed as a spare, this valve resulted in a faster cutoff and caused cutoff impulse to decrease.

b. At engine J-2060, the change to nominal calibration point of 230,000 pounds thrust raised cutoff impulse.

c. On engines incorporating MD211 or MD319 change, addition of filters to the fast-shutdown valve slowed cutoff and caused cutoff impulse to increase.

8-53A. DETERMINATION OF CUTOFF IMPULSE USING THRUST CHAMBER PRESSURE MEASUREMENT. The thrust chamber pressure measurement can be used to determine thrust during the cutoff transient when a correction for the response of the transducer is included. The correction is obtained by means of the relationship between the ratios of the thrust chamber pressure at any time after cutoff signal, to the thrust chamber pressure value at cutoff signal, and the vacuum thrust value at any time after cutoff signal, to the thrust value at cutoff signal. (See figure 8-53.) The vacuum thrust at the cutoff signal is calculated by using the steady-state data reduction program. The ratio of thrust chamber pressure to the value at cutoff signal is determined using the measured chamber pressure. The thrust any time after cutoff is determined by using figure 8-53. For testing under sea-level conditions, the impulse to 5 percent of rated thrust is calculated by integration of thrust values from cutoff signal to 5 percent of rated thrust; 6,400 pound-seconds are added to obtain the impulse to zero thrust. For flight and testing under vacuum conditions, the impulse to zero thrust is calculated directly by integration of thrust values starting at the time of the cutoff signal.

8-53B. For comparison to cutoff impulse, the actual impulse must be standardized. The standard conditions are: null propellant utilization valve position; main oxidizer valve actuator temperature of 0° F; and standard inlet conditions, pressurization, flowrates, and auxiliary power extraction. The equation for standardization is:

$$I_{standard} = I_{actual} \left(\frac{F_{standard}}{F_{actual}} \right) - \Delta I$$

where

I_{actual} = actual cutoff impulse in pound-seconds

$I_{standard}$ = cutoff impulse in pound-seconds, at null propellant utilization valve position and standard conditions

ΔI = delta cutoff impulse (from figure 8-54) in pound-seconds, at actual main oxidizer valve actuator temperature

F_{actual} = cutoff thrust in pounds, at actual conditions

$F_{standard}$ = cutoff thrust in pounds, at null propellant utilization valve position and standard conditions

8-53C. Flight Prediction of Cutoff Impulse. The predicted cutoff impulse for a flight is determined using the following equation:

$$I_{actual} = (I_{standard} + \Delta I)\left(\frac{F_{Actual}}{F_{standard}}\right)$$

The symbols are the same as defined in paragraph 8-53B.

Example:

$I_{standard}$	= 40,500 pound-seconds	*Cutoff impulse to zero thrust,* obtained from engine acceptance tests
$F_{standard}$	= 205,000 pounds	Thrust at null propellant utilization valve position and standard altitude conditions, obtained from engine acceptance tests
F_{actual}	= 180,000 pounds	Cutoff thrust predicted for flight
ΔI	= 7,000 pound-seconds	For main oxidizer valve actuator temperature of -150° F at cutoff, (predicted for flight)

Therefore:

$$I_{actual} = (40,500 + 7,000)\left(\frac{180,000}{205,000}\right)$$

$$= 41,700 \text{ pound-seconds}$$

8-54. CUTOFF PROPELLANT CONSUMPTION. During the transient period from engine cutoff signal at null PU to zero thrust, the engine consumes maximum of approximately nine gallons of oxidizer and 55 gallons of fuel. This information should be used to avoid a propellant depletion condition during engine cutoff.

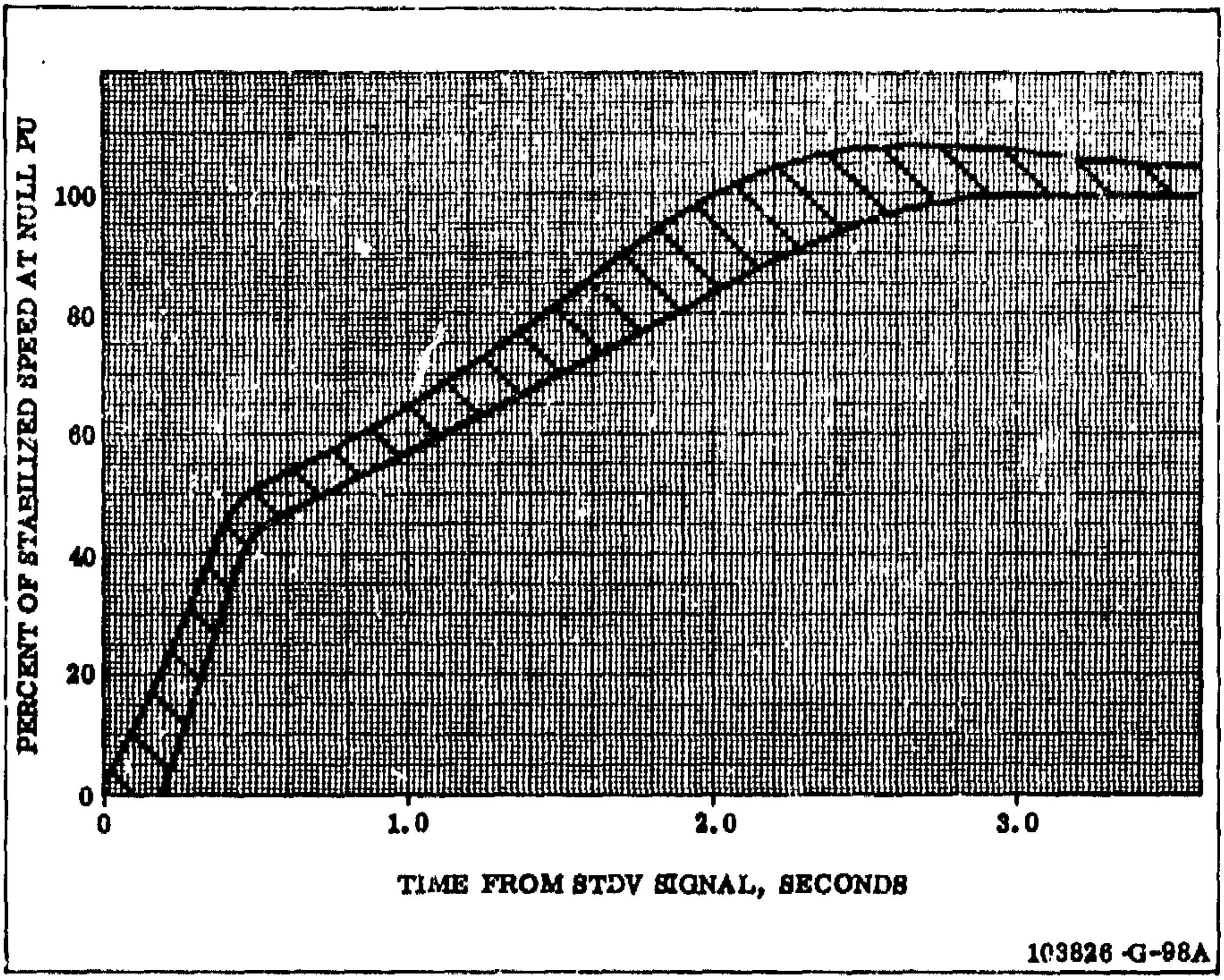

Figure 8-44. Fuel Turbopump Speed Increase (Engines J-2025 Through J-2059)

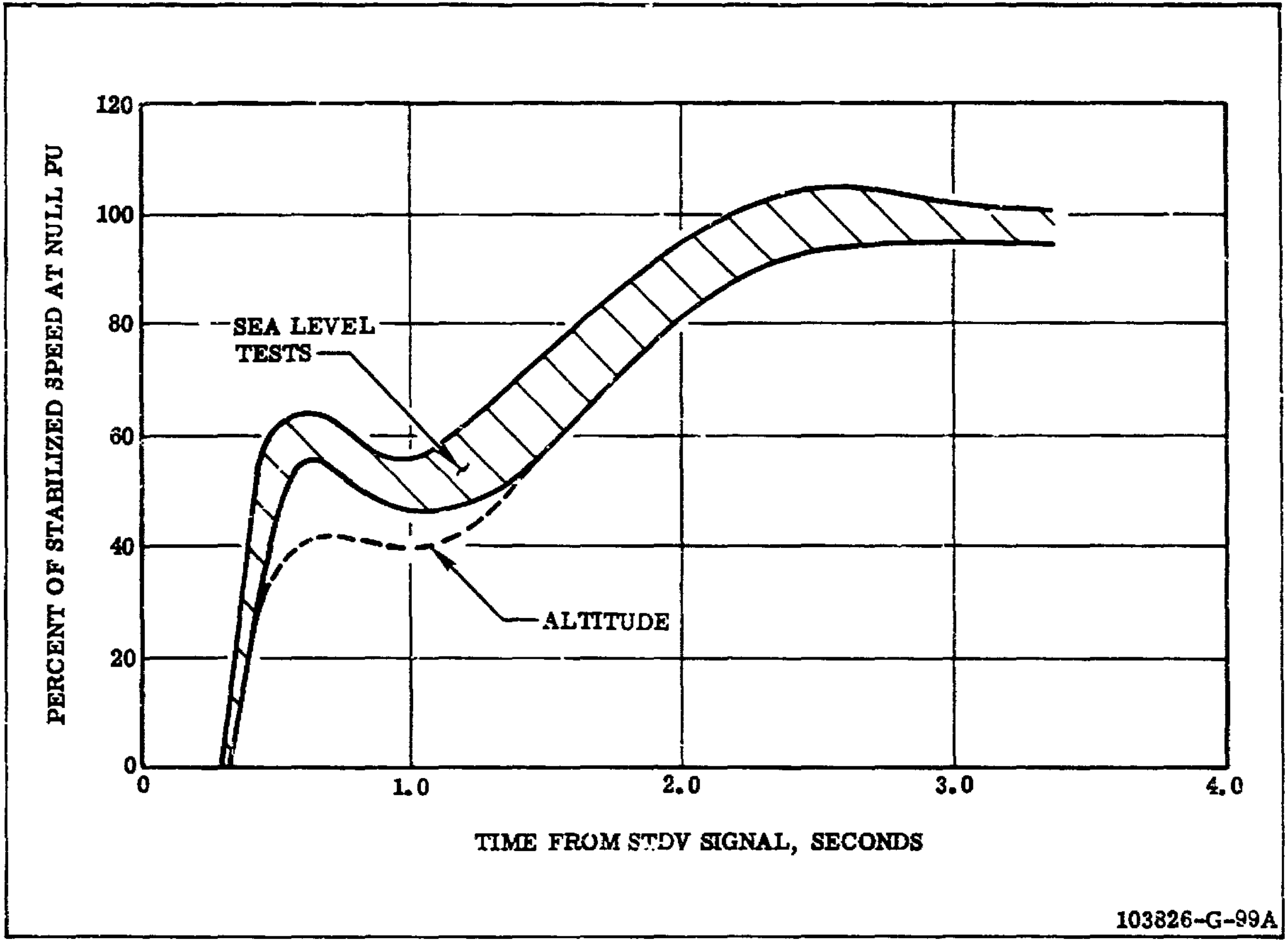

Figure 8-45. Oxidizer Turbopump Speed Increase (Engines J-2025 Through J-2059)

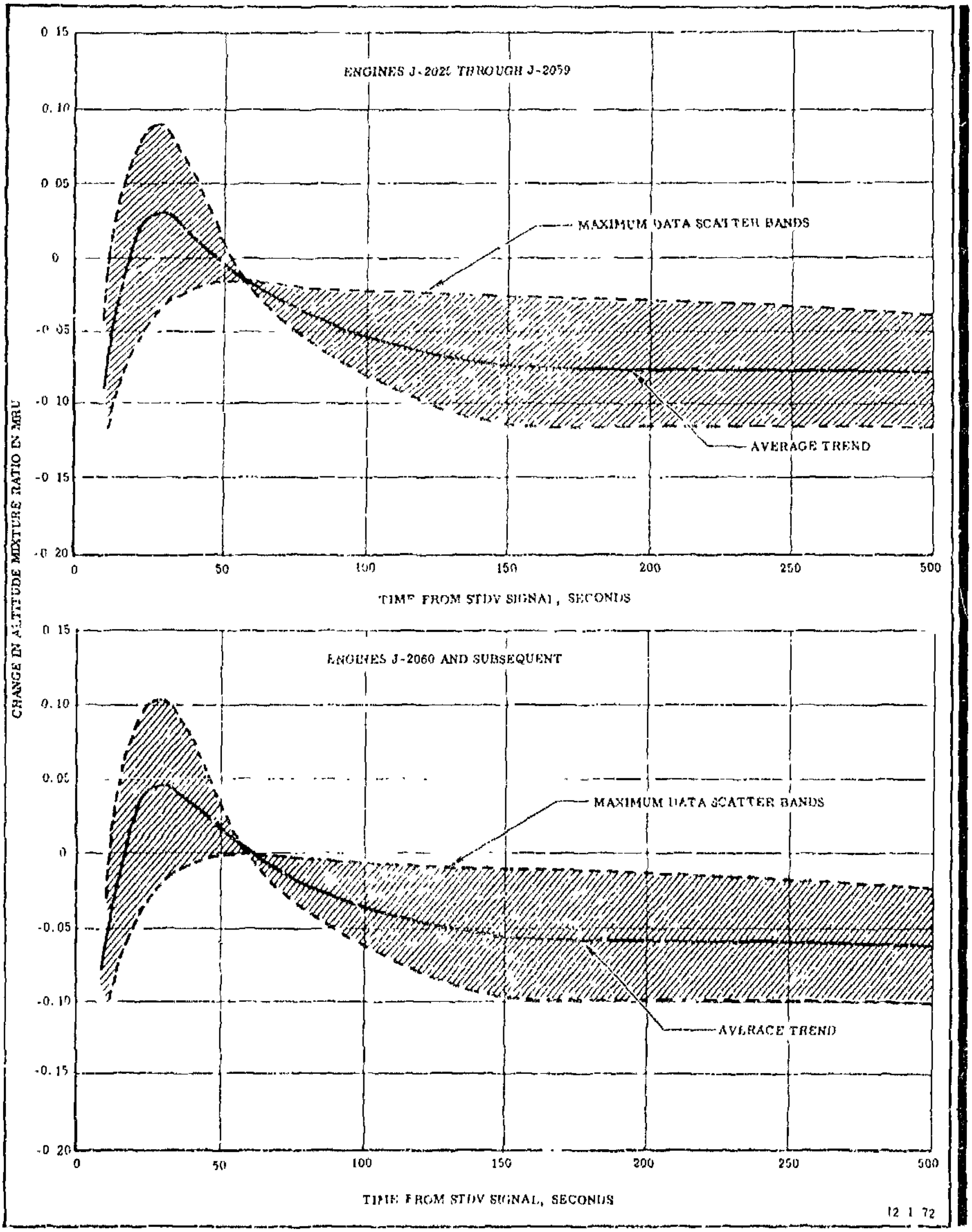

Figure 8-46. In-Test Engine Mixture Ratio Repeatability

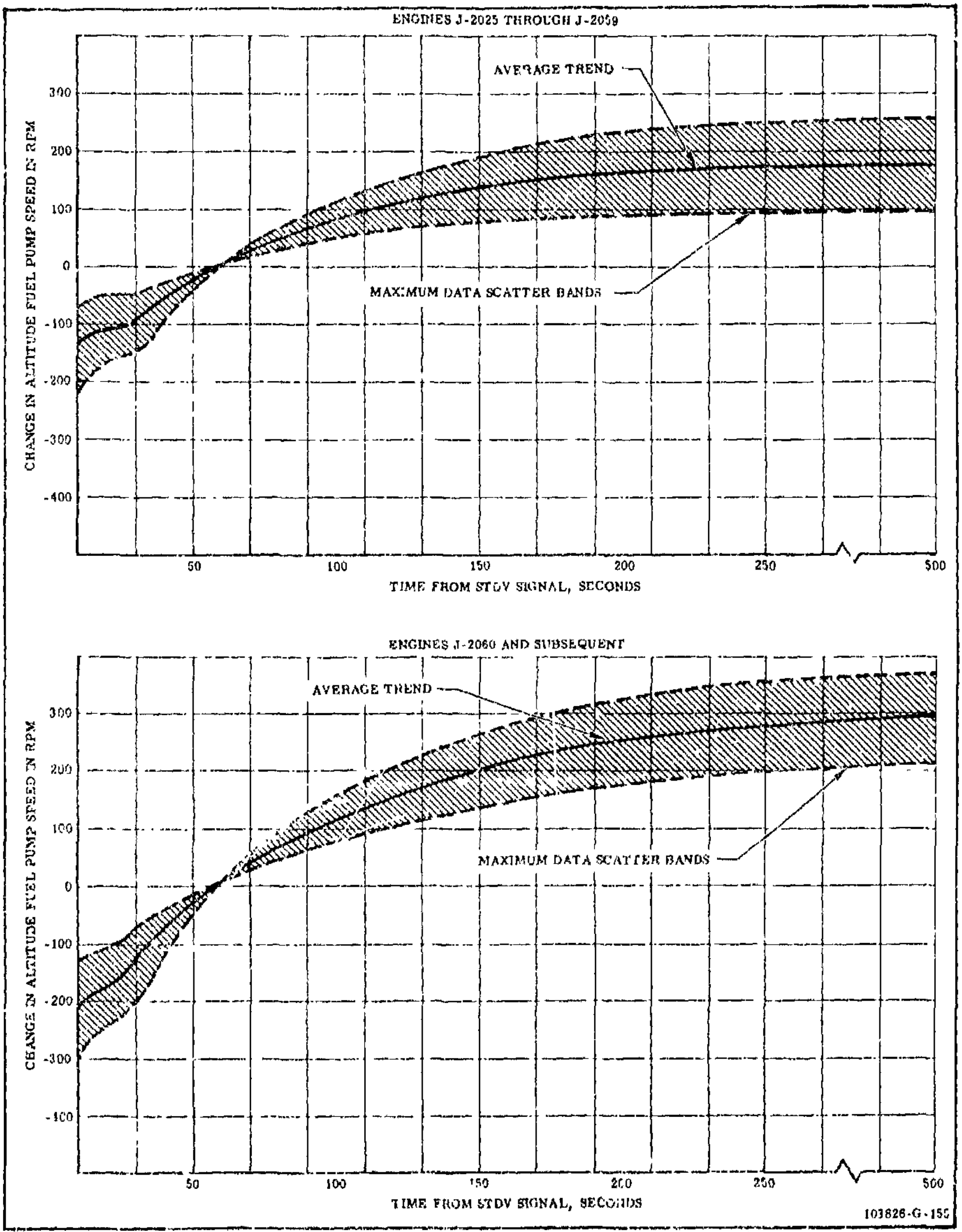

Figure 8-47. In-Test Fuel Pump Speed Repeatability

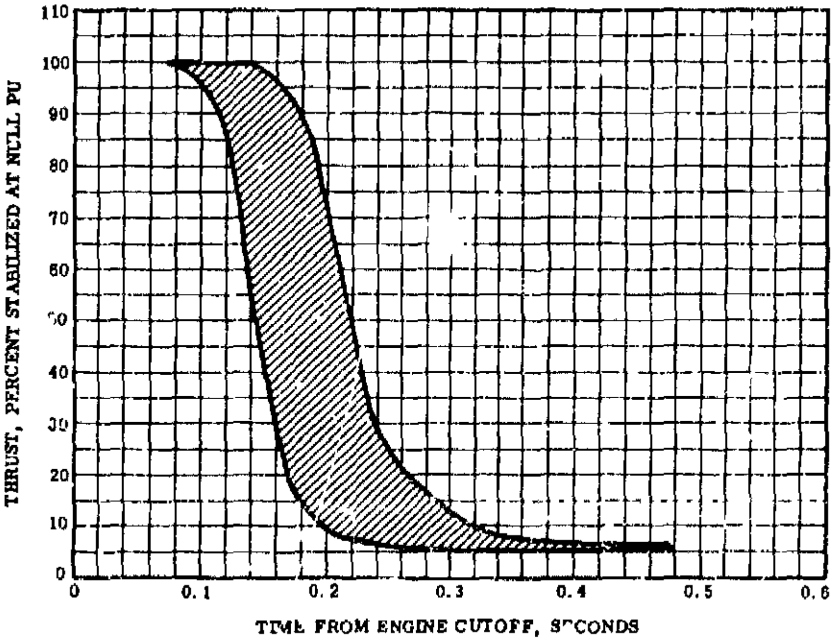

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Figure 8-48. Thrust Decrease (Engines J-2025 Through J-2047) Fast-Shutdown Valve 556970 (MD19 Change) or 556936 (MD149 Change)

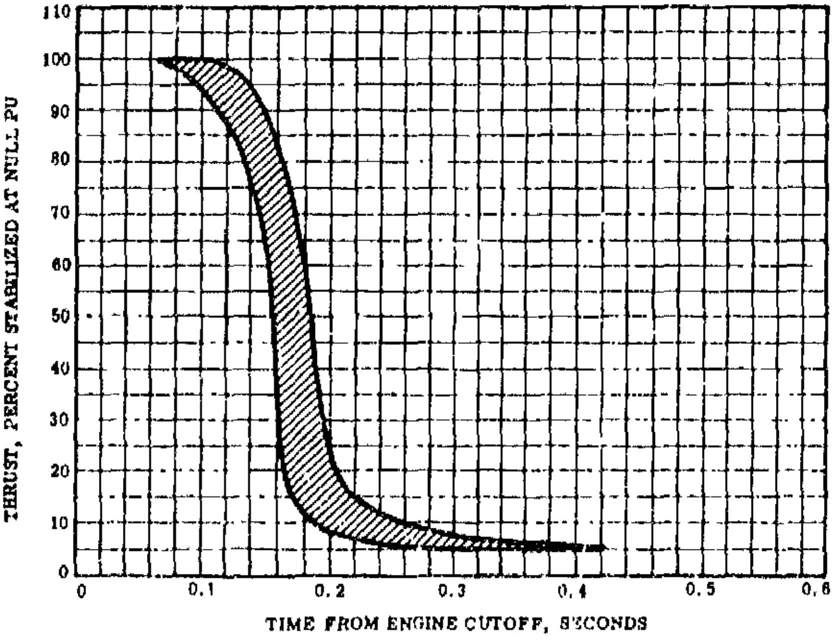

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Figure 8-49. Thrust Decrease (Engines J-2048 Through J-2059) Fast-Shutdown Valve 557817 (MD154 Change)

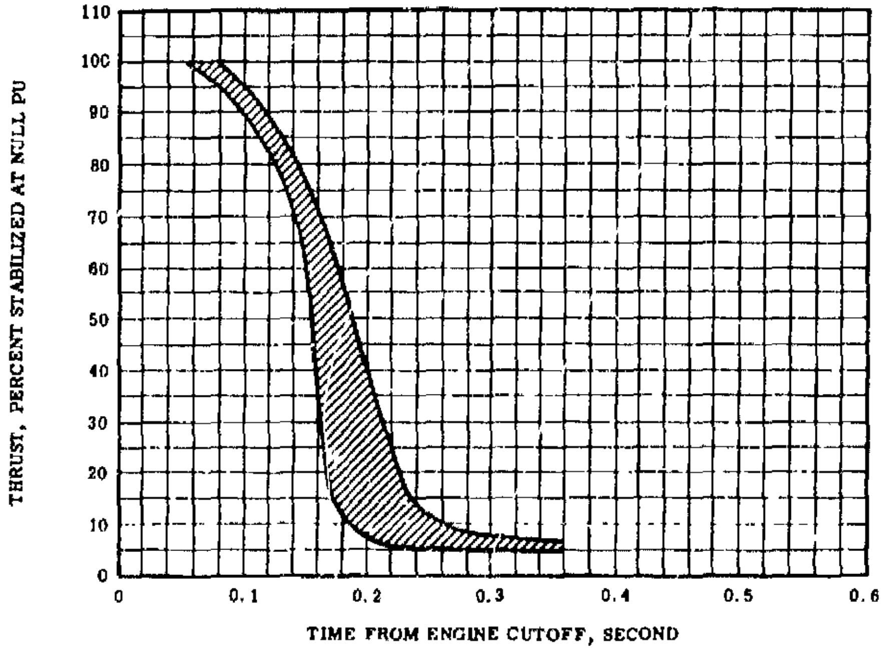

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Figure 8-50. Thrust Decrease (Engines J-2060 Through J-2071 and J-2074 Through J-2082) Fast-Shutdown Valve 557817 (MD154 Change)

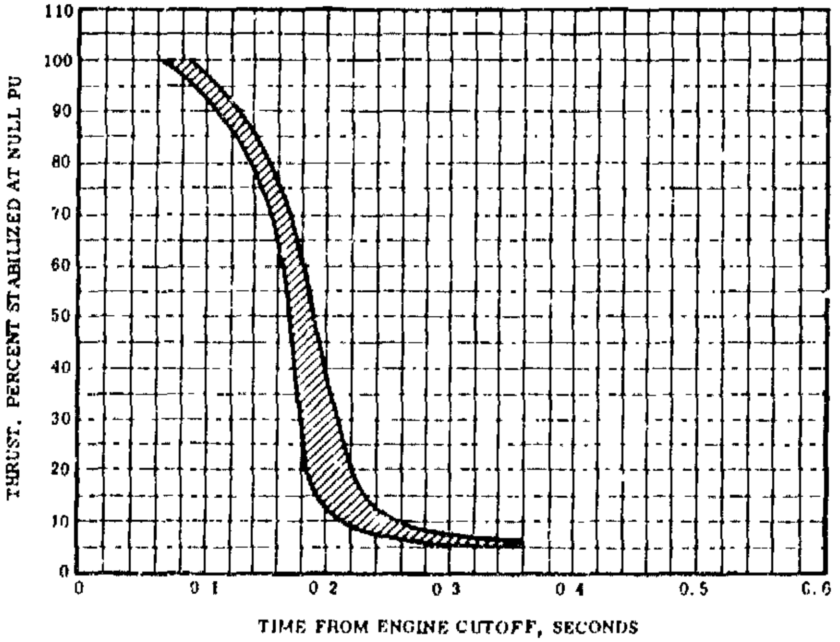

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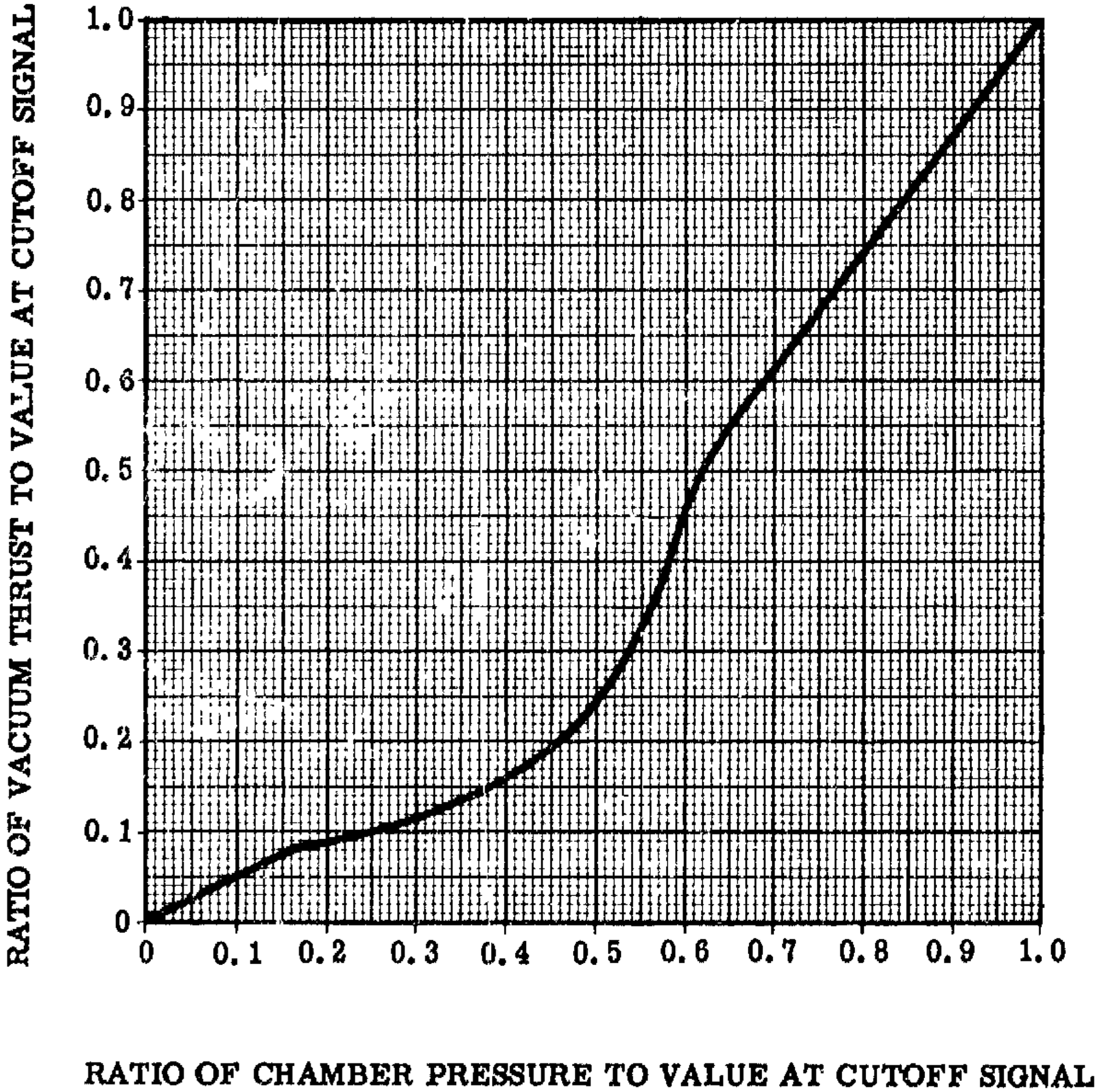
Figure 8-51. Thrust Decrease (Engines J-2072, J-2073, and J-2083 and Subsequent) Fast-Shutdown Valve 558127 (MD211 Change)

	Engines J-2012 thru J-2047		Engines J-2048 thru J-2059		Engines J-2060 thru J-2071 and J-2074 thru J-2082		Engines J-2072, J-2073, J-2083, and Subsequent	
	Time to 5% Thrust (seconds)	Cutoff(a) Impulse lb-sec	Time to 5% Thrust (seconds)	Cutoff(a) Impulse lb-sec	Time to 5% Thrust (seconds)	Cutoff(a) Impulse lb-sec	Time to 5% Thrust (seconds)	Cutoff(a) Impulse lb-sec
Mean	0.340	35,700	0.330	32,200	0.350	32,900	0.340	34,100
Standard deviation (overall)	0.030	2,000	0.042	1,150	0.034	1,340	0.030	1,300
Standard deviation (run-to-run)		1,330		880		970		760
Pressure-activated (fast-shutdown) valve on engine during engine acceptance test.	556970 (MD19 change) or 556936 (MD149 change)		557817 (MD154 change)				558127 (MD211 change)	
If fast-shutdown valve is replaced, Engine Logbook cutoff impulse value should be corrected by:	(557817) replaced by MD154	-3500					-1200	
	(558127) replaced by MD211	-2300		+1200				

(a) Cutoff values are based on a main oxidizer valve temperature of 0°F, with propellant utilization valve in null position, and are defined from cutoff signal to 5% of rated thrust. To obtain impulse to zero thrust, add 6,400 lb-sec to these values.

Figure 8-52. Summary of Cutoff Impulse Characteristics



J2-1-51

Figure 8-53. Empirical Curve for Calculating Thrust Using Chamber Pressure During Cutoff Transient

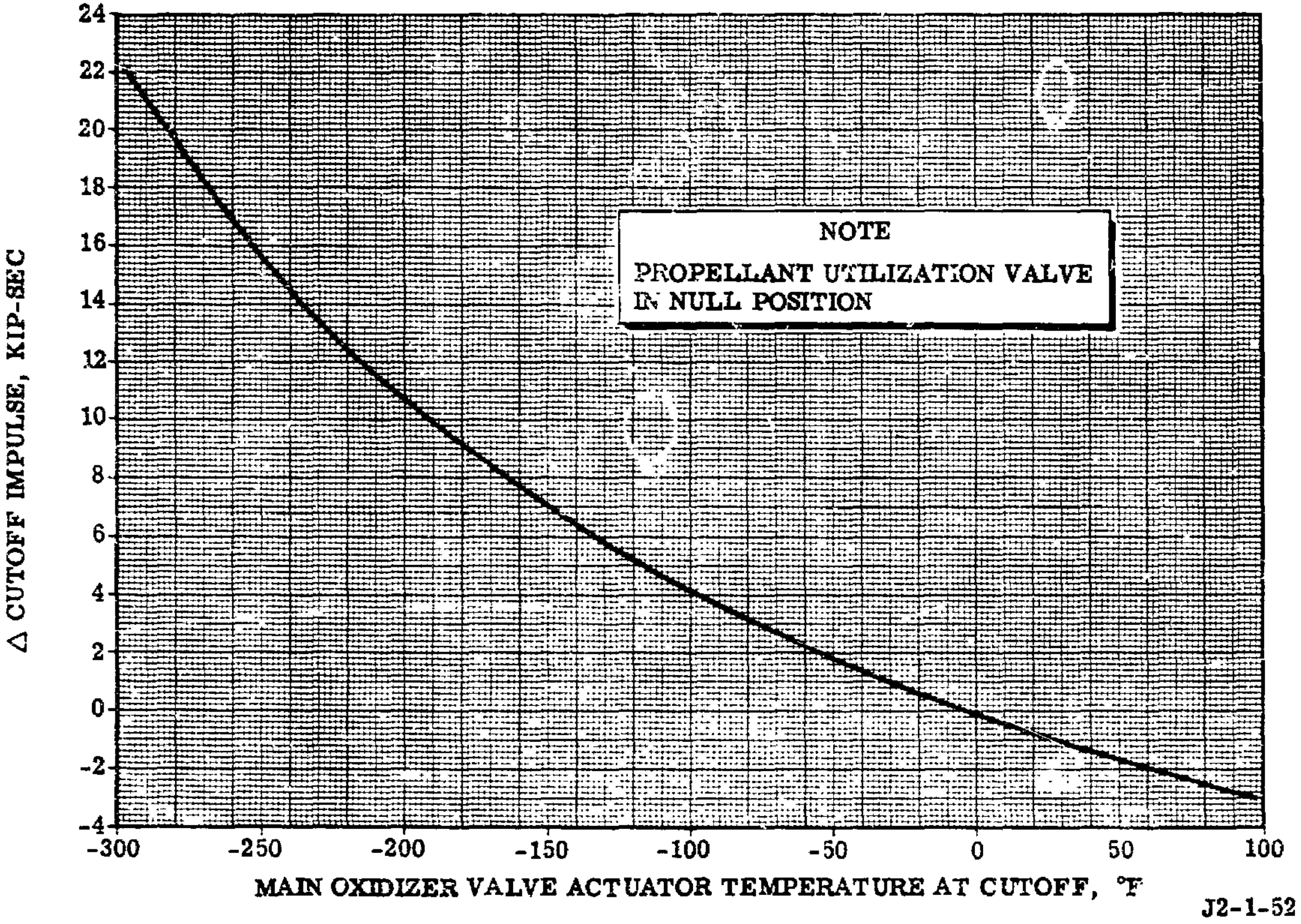


Figure 8-54. Effect of Main Oxidizer Valve Temperature on Cutoff Impulse

8-55. TURBOPUMP SPEED DECAY AT CUTOFF. The estimated turbopump speed decay from cutoff signal is based on the assumption that liquid propellants are present within the pumps. Estimated decay time from the nominal steady-state operation to zero rpm is ten seconds for fuel and four seconds for oxidizer.

8-56. EFFECTS OF ACCESSORY DRIVE. The accessory drive pad is structurally designed for 30 horsepower extraction at mainstage speed. The engine performance balance is based on the extraction of 15 horsepower. The 15-horsepower value was selected based upon the nominal power required to gimbal the engine at model specification limits. Variations in this power and the resulting variations in other performance figures may be calculated using the influence coefficients in figures 8-19 and 8-20. Engine performance may be balanced for any desired accessory power extraction (30 horsepower, maximum) if so dictated by vehicle requirements.

8-57. ENGINE THRUST RESULTING FROM RESTART FUEL CHILLDOWN.

8-58. The estimated maximum fuel flow is approximately four pounds per second of liquid hydrogen at the end of the engine restart chilldown phase. This fuel flow is calculated from the pressure drop between the main fuel tank and the thrust chamber, less hydraulic resistance. This fuel flow will cause a maximum chamber pressure of approximately 2.7 psi with a corresponding thrust of 680 pounds. The initial flow and corresponding chamber pressure and thrust will be negligible, since the liquid hydrogen will gasify in the lines, but will increase to the approximate maximum values given above prior to completion of the chilldown phase. Similar calculations for the augmented spark igniter indicate a thrust of approximately nine pounds. The values noted above were based on the following assumptions: chamber temperature is at 200^0 F, thrust coefficient equals 1.5, hydrogen entering the chamber is all gas, and the chamber flows full at the indicated chamber pressure.

SECTION IX

MASS PROPERTIES AND DESIGN LOAD CRITERIA

TABLE OF CONTENTS

Underlined titles denote primary paragraphs.

9-1. SCOPE. This section contains engine weight, gimbaled mass, center of gravity, and moment of inertia data for the J-2 engine. Information for determining maximum permissible loads at the engine-to-vehicle interface is also presented.

9-2. MASS PROPERTIES.

9-3. The engine weight, gimbaled mass, center of gravity, and moment of inertia data for the basic engine and accessories are shown in figures 9-1 through 9-4. Separate tables are provided to differentiate the various flight configurations and the static test configuration. These figures represent maximum values as limited by the engine model specification. For additional data, refer to the current J-2 Program Quarterly Progress Report R-7800. The shipping weight and center of gravity are shown in figure 9-5.

9-4. On 225K engines, the fuel turbopump polar moment of inertia is 2.86 lb/in/sec^2 (rotating hardware plus fluid) and the oxidizer turbopump polar moment of inertia is 4.36 lb/in/sec^2 (rotating hardware plus fluid). On 230K engines, the fuel turbopump polar moment of inertia is 3.10 lb/in/sec^2 (rotating hardware plus fluid) and the oxidizer turbopump polar moment of inertia is 4.59 lb/in/sec^2 (rotating hardware plus fluid).

9-5. A reference coordinate axis diagram is shown in figure 9-6.

9-6. DESIGN LOAD CRITERIA.

9-7. The following paragraphs present the information necessary to determine maximum permissible loads at the engine-to-vehicle interfaces.

9-8. PROPELLANT INLET DUCT AND GIMBAL BEARING INTERFACE.

9-9. Permissible resultant loads at the gimbal and inlet line interfaces are presented in influence coefficient form so that compatible loads for any particular set of variables can be easily calculated.

Description	Spec Weight (Lb)	Center of Gravity (Inches)			Axis System Orientation	Origin of Axes (Inches)			Moment of Inertia (Slug-ft^2)		
		Y	X	Z		Y	X	Z	Iy	Ix	Iz
Rocket Engine and Accessories (dry)	3,331	+32.3	-0.1	+1.2	Engine	+32.3	-0.1	+1.2	410	906	864
Rocket Engine and Accessories (burnout)	3,404	+31.9	+0.1	+0.9	Engine	+31.9	+0.1	+0.9	418	919	875
Rocket Engine and Accessories (wet)	3,436	+31.9	+0.1	+1.0	Engine	+31.9	+0.1	+1.0	421	930	887
Rocket Engine and Accessories (dry)	3,331	+32.3	+0.8	+0.9	Gimbal	+32.3	+0.8	+0.9	410	884	887
Rocket Engine and Accessories (burnout)	3,404	+31.9	+0.7	+0.6	Gimbal	+31.9	+0.7	+0.6	418	897	896
Rocket Engine and Accessories (wet)	3,436	+31.9	+0.7	+0.6	Gimbal	+31.9	+0.7	+0.6	421	908	909

NOTE: Data does not include customer-furnished equipment, but includes 68 pounds of insulation.

Figure 9-1. Weight, Center of Gravity, and Moment of Inertia (Flight Condition) SII Stage Inboard Configuration

Description	Spec Weight (Lb)	Center of Gravity (Inches)			Axis System Orientation	Origin of Axes (Inches)			Moment of Inertia (Slug-ft^2)		
		$\bar{Y}$	$\bar{X}$	$\bar{Z}$		$\bar{Y}$	$\bar{X}$	$\bar{Z}$	Iy	Ix	Iz
Rocket Engine and Accessories (dry)	3,584	+29.9	-0.1	+1.0	Engine	+29.9	-0.1	+1.0	437	986	925
Rocket Engine and Accessories (burnout)	3,713	+29.1	+0.1	+1.5	Engine	+29.1	+0.1	+1.5	452	1,018	942
Rocket Engine and Accessories (wet)	3,745	+29.1	+0.1	+1.4	Engine	+29.1	+0.1	+1.4	452	1,018	942
Rocket Engine and Accessories (dry)	3,584	+29.9	+0.7	+0.7	Gimbal	+29.9	+0.7	+0.7	437	952	959
Rocket Engine and Accessories (burnout)	3,713	+29.1	+1.1	+1.0	Gimbal	+29.1	+1.1	+1.0	452	974	986
Rocket Engine and Accessories (wet)	3,745	+29.1	+1.1	+1.0	Gimbal	+29.1	+1.1	+1.0	452	974	986
Gimbaled Mass (dry)	3,356	+31.3	+0.6	+0.7	Engine	0.0	0.0	0.0	398	1,574	1,521
Gimbaled Mass (wet)	3,487	+30.7	+0.8	+1.3	Engine	0.0	0.0	0.0	432	1.642	1,578
Gimbaled Mass (dry)	3,356	+31.3	+0.9	0.0	Gimbal	0.0	0.0	0.0	398	1,541	1,554
Gimbaled Mass (wet)	3,487	+31.2	+0.8	-0.1	Gimbal	0.0	0.0	0.0	432	1,600	1,620

NOTE: Data does not include customer-furnished equipment, but includes 92 pounds of insulation.

Figure 9-2. Weight, Center of Gravity, and Moment of Inertia (Flight Condition) SII Stage Outboard Configuration

Description	Spec Weight (Lb)	Center of Gravity (Inches)			Axis System Orientation	Origin of Axes (Inches)			Moment of Inertia (Slug-ft^2)		
		$\overline{Y}$	$\overline{X}$	$\overline{Z}$		$\overline{Y}$	$\overline{X}$	$\overline{Z}$	Iy	Ix	Iz
Rocket Engine and Accessories (dry)	3,536	+29.8	-0.2	+1.2	Engine	+29.8	-0.2	+1.2	428	968	905
Rocket Engine and Accessories (burnout)	3,665	+29.0	-0.1	+1.7	Engine	+29.0	-0.1	+1.7	443	998	922
Rocket Engine and Accessories (wet)	3,697	+28.9	0.0	+1.6	Engine	+28.9	0.0	+1.6	446	1,009	932
Rocket Engine and Accessories (dry)	3,536	+29.8	+0.7	+1.0	Gimbal	+29.8	+0.7	+1.0	428	933	940
Rocket Engine and Accessories (burnout)	3,665	+29.0	+1.1	+1.2	Gimbal	+29.0	+1.1	+1.2	443	954	966
Rocket Engine and Accessories (wet)	3,697	+28.9	+1.1	+1.2	Gimbal	+28.9	+1.1	+1.2	446	964	976
Gimbaled Mass (dry)	3,308	+31.2	+0.5	+0.9	Engine	0.0	0.0	0.0	389	1,542	1,487
Gimbaled Mass (wet)	3,469	+30.3	+0.6	+1.4	Engine	0.0	0.0	0.0	408	1,576	1,505
Gimbaled Mass (dry)	3,308	+31.2	+1.0	+0.3	Gimbal	0.0	0.0	0.0	389	1,508	1,521
Gimbaled Mass (wet)	3,469	+30.3	+1.4	+0.5	Gimbal	0.0	0.0	0.0	408	1,531	1,550

NOTE: Data does not include customer-furnished equipment, but includes 44 pounds of insulation.

Figure 9-3. Weight, Center of Gravity, and Moment of Inertia (Flight Condition) SIVB Stage Configuration

Description	Spec Weight + Current Test Equipment(a) (Lb)	Center of Gravity (Inches)			Axis System Orientation	Origin of Axes (Inches)			Moment of Inertia (Slug-ft^2)		
		$\overline{Y}$	$\overline{X}$	$\overline{Z}$		$\overline{Y}$	$\overline{X}$	$\overline{Z}$	Iy	Ix	Iz
Rocket Engine and Accessories (dry)	3,967	+35.1	0.0	+2.9	Engine	+35.1	0.0	+2.9	577	1,312	1,257
Rocket Engine and Accessories (burnout)	4,102	+34.3	+0.1	+3.2	Engine	+34.3	+0.1	+3.2	593	1,358	1,291
Rocket Engine and Accessories (wet)	4,134	+34.2	+0.2	+3.2	Engine	+34.2	+0.2	+3.2	595	1,369	1,300
Rocket Engine and Accessories (dry)	3,967	+35.1	+2.0	+2.0	Gimbal	+35.1	+2.0	+2.0	577	1,281	1,288
Rocket Engine and Accessories (burnout)	4,102	+34.3	+2.4	+2.2	Gimbal	+34.3	+2.4	+2.2	593	1,319	1,330
Rocket Engine and Accessories (wet)	4,134	+34.2	+2.4	+2.2	Gimbal	+34.2	+2.4	+2.2	595	1,329	1,340
Gimbaled Mass (dry)	3,739	+36.7	+0.6	+2.7	Engine	0.0	0.0	0.0	544	2,268	2,215
Gimbaled Mass (wet)	3,876	+36.0	+0.8	+3.2	Engine	0.0	0.0	0.0	562	2,313	2,248
Gimbaled Mass (dry)	3,739	+36.7	+2.4	+1.5	Gimbal	0.0	0.0	0.0	544	2,235	2,248
Gimbaled Mass (wet)	3,876	+36.0	+2.8	+1.8	Gimbal	0.0	0.0	0.0	562	2,272	2,290

(a) Test equipment includes side-load stabilizer, T-ring stiffener, release couplings, water-cooled diffuser, and static-stage-test instrumentation.

NOTE: Data does not include customer-furnished equipment or thermal insulation.

Figure 9-4. Weight, Center of Gravity, and Moment of Inertia (Sea-Level Test Condition) SII Stage Outboard or SIVB Stage Configuration

Description	Spec Weight (lb)	Center of Gravity (Inches)		
		$\overline{Y}$	$\overline{X}$	$\overline{Z}$
(1) Rocket Engine and Accessories, 230K, (dry)	3,492	+29.0	-0.2	+1.2
(2) Thrust Chamber Exit Closure	+38	+116.6	0.0	0.0
(3) Desiccant, T/C (128 units)	+9	+115.0	0.0	0.0
(4) Thrust Chamber Covers (4)	+62	+81.4	0.0	0.0
(5) Miscellaneous Supports and Covers	+145	+1.4	-9.6	+0.8
(6) Static-Stage Instrumentation	+40	+35.1	+19.1	-2.1
Total (1 through 6)	(3,786)	(+29.9)	(-0.4)	(+1.1)

Figure 9-5. Weight and Center of Gravity (Engine With Shipping Closures Installed)

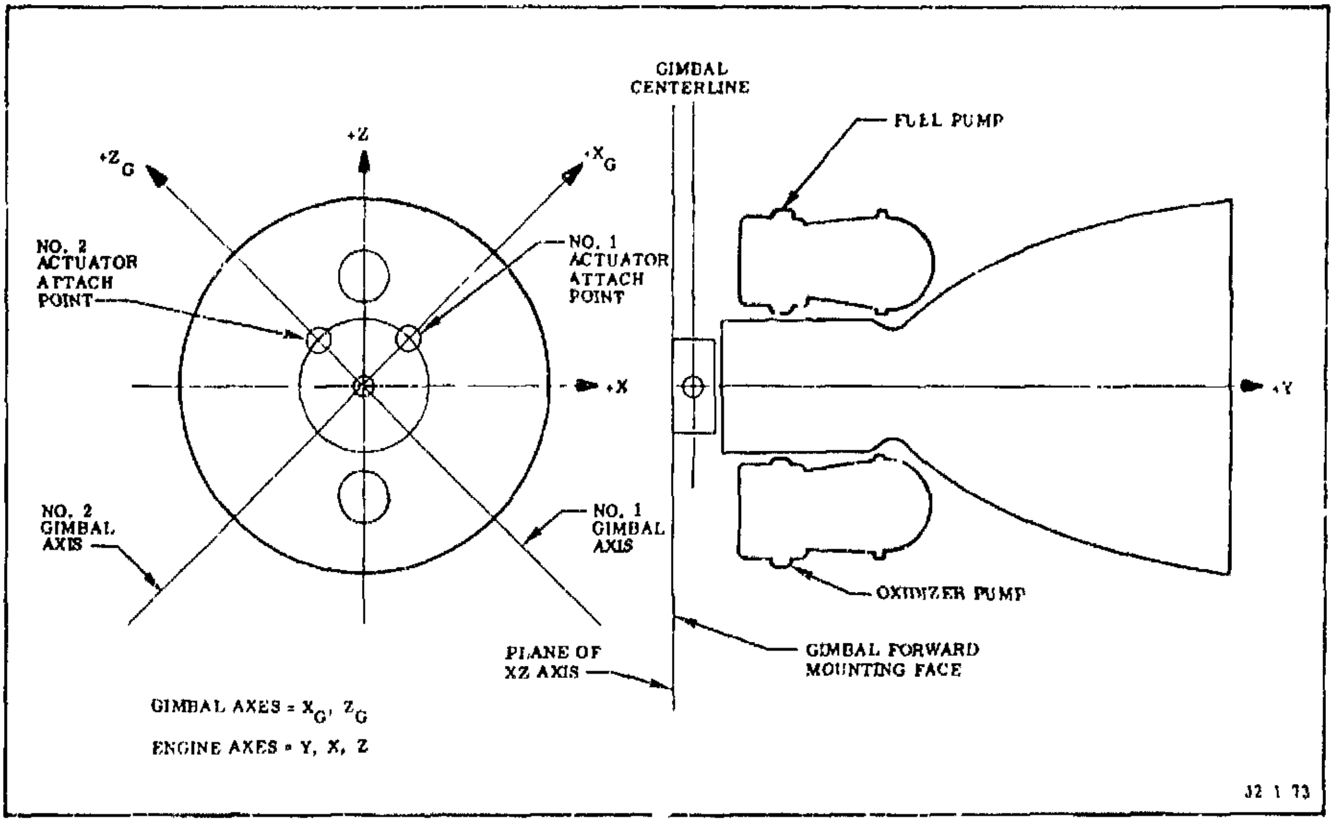


Figure 9-6. Coordinate Axis Diagram

		F_{1A}	F_{2A}	A_{LAT} cos θ	A_{LAT} sin θ	A_{LONG}	KF_N	I_x	I_θ	I_ψ	CASE I GIMBAL INTERFACE						CASE II GIMBAL INTERFACE			
											OXIDIZER INLET LINE			FUEL INLET LINE			OXIDIZER INLET LINE			
											TQ_I	P_I	C_I	TQ_F	P_F	C_F	TQ_I	P_I	C_I	T
Position 1	F_x	-1.295-1	-1.295-1	-1.791+3	-0.000+0	-3.796+1	6.666-3	3.858-3	8.720-3	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0
	F_y	-9.952-1	-9.961-1	-3.790+1	-1.338+1	3.303+3	-1.858-5	-4.511-5	0.000+0	-1.000+0	0.000+0	2.103+2	-1.032+3	0.000+0	-3.592+1	-6.547+2	0.000+0	2.102+2	-1.032+3	0
	F_z	1.237-1	-1.237-1	0.000+0	-1.864+3	1.937+1	-6.367-3	-3.681-3	-8.720-3	0.000+0	0.000+0	-5.585+0	2.767+2	0.000+0	-5.607+0	3.387+2	0.000+0	-6.585+0	2.767+0	0
	M_x	-4.331+1	1.131-1	0.000+0	-5.527+3	-6.780+1	4.512-1	-1.289-2	3.054-2	0.000+0	0.000+0	2.301+1	9.686+2	0.000+0	-2.312+1	1.165+3	0.000+0	-2.304+1	9.646+2	0
	M_y	3.921-2	1.108-1	-6.997+2	1.361+3	2.894+1	7.248-3	4.191-3	-0.000+0	-0.000+0	-1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	-1.000+0	0.000+0	0.000+0	-1
	M_z	-4.535-1	-4.535-1	1.279+3	0.000+0	-1.328+2	1.086-1	-1.350-2	-3.051-2	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0
Position 2	F_x	-1.435+1	1.283+1	-1.794+3	-5.987+0	-3.748+1	-6.666-3	-3.858-3	-8.726-3	0.000+0	-7.604-3	0.000+0	0.000+0	-8.211-3	-0.000+0	-0.000+0	-8.235-3	0.000+0	0.000+0	1
	F_y	-9.688-1	-9.701-1	-3.731+1	-2.901+2	3.310+3	1.094-3	6.331-4	1.606-3	-9.829-1	0.000+0	1.981+2	8.998+3	0.000+0	-8.155+1	-4.124+3	0.000+0	1.936+2	-8.021+3	0
	F_z	-1.808-1	-1.810-1	-6.986+0	-1.922+3	2.901+2	-6.271-3	3.630-3	-8.577-3	1.840-1	0.000+0	1.339+1	-6.193+2	0.000+0	-1.012+1	2.231+2	0.000+0	7.575+0	2.178+2	0
	M_x	6.328-1	-6.337-1	-2.445+1	6.730+3	1.015+3	4.539-1	-1.270-2	3.002-2	-6.341-1	0.000+0	4.867+1	-2.272+3	0.000+0	3.817+1	7.811+2	0.000+0	2.651+1	7.621+2	0
	M_y	-1.031+0	1.286+0	6.871+2	1.206+3	2.712+2	8.602-2	4.122-3	-0.000+0	-0.000+0	-8.334-1	0.000+0	0.000+0	-1.173+0	-0.000+0	-0.000+0	-8.213-1	0.000+0	0.000+0	1
	M_z	2.982-1	-2.078-1	6.150+3	2.503+2	-7.984+1	-3.939-1	1.427-2	3.054-2	0.000+0	1.278-1	0.000+0	0.000+0	1.886-1	-0.000+0	-0.000+0	1.246-1	0.000+0	0.000+0	-1
Position 3	F_x	1.024+1	1.610-1	-1.800+3	9.910+0	1.071+2	6.653-3	-3.850-3	-8.726-3	9.242-2	-1.524-3	-9.456+0	3.310+2	-3.563-3	6.711+0	-2.235+2	4.773-3	-1.891+0	-8.145+1	-1
	F_y	-9.937-1	-9.900-1	1.071+2	-1.565+2	3.337+3	1.124-3	6.507-4	8.065-4	-9.911-1	8.141-3	2.076+2	-4.685+3	1.892-3	8.817+1	2.389+3	-3.922-4	2.031+2	-1.758+3	1
	F_z	-1.572+1	1.517-1	9.146+0	1.884+3	1.565+2	6.290-3	-3.640-3	8.689-3	-9.202-2	-4.157-3	4.223+0	-3.217+2	-3.527-3	-6.419+0	2.273+2	1.861-3	1.741+0	8.411+1	-4
	M_x	-5.503+1	-5.312-1	3.481+1	6.595+3	5.479+2	-1.540-1	-1.274-2	-3.041-2	-3.220-1	-1.455-2	3.228+1	-1.136+3	1.231-2	-2.257+1	7.956+2	-1.701-2	6.094+0	2.943+2	-1
	M_y	-6.125-1	6.264-1	-6.992+2	-3.805+3	-3.334+2	2.936-2	-6.112-3	0.000+0	0.000+0	-9.050-1	8.326+1	-1.333+3	1.078+0	9.518+1	-6.874+3	-9.051-1	-7.220+1	4.311+3	1 1
	M_z	3.018-1	-5.059-1	6.234+3	2.903+2	3.415+2	-1.073-1	1.290-2	3.054-2	-3.234-1	-6.812-2	4.087+1	-1.560+3	-8.760-2	1.400+1	2.374+2	6.725-2	7.762-2	6.850+2	-8
Position 4	F_x	-6.049-2	1.867-1	-1.833+3	0.000+0	-2.196+2	-6.582-3	3.809-3	-8.720-3	1.840-1	-8.387-1	-1.770+1	2.723+2	2.011-1	1.227+1	-5.681+2	-1.177-1	-5.917+0	-2.082+2	-1 4
	F_y	-1.015+0	-1.006+0	2.495+3	-1.914+1	2.329+3	1.151-3	6.661-4	0.000+0	-9.820-1	1.541-2	2.141+2	-8.894+2	4.061-3	-9.580+1	-2.366+2	2.371+3	2.219+2	-1.208+3	2
	F_z	-1.236-1	-1.236+1	0.000+0	-1.833+3	-1.337+1	-6.367-3	-3.681-3	-8.726-3	-0.000+0	-8.839-3	8.942-9	1.421+6	-7.351-3	1.387-7	-1.090+6	9.513+3	1.005-7	-2.306-6	-9
	M_x	-4.326-1	-4.327-1	0.000+0	-6.593+3	6.780+1	-4.512-1	-1.289-2	-3.054-2	0.000+0	-3.093-2	3.129-8	4.973-6	-2.642-2	4.157-7	-1.128+5	3.310-2	3.520-7	-8.071-5	-1 1
	M_y	-2.135-1	-1.555-1	-7.111+2	-9.153+3	2.461+1	-2.837-2	-1.641-2	-0.000+0	0.000+0	-9.977-1	1.187+2	-4.800+3	-1.012+0	1.582+2	-1.215+4	-1.014+0	-1.078+2	5.023+3	-1
	M_z	2.117+1	-6.604+1	6.418+3	0.000+0	8.738+2	-4.083-1	1.333-2	3.054-2	-6.141-1	2.935-3	6.196+1	-9.531+2	7.019-4	-1.297+1	1.988+3	4.121-4	2.071+1	7.269+2	5
Position 5	F_x	-8.975-2	1.598-1	-1.809+3	-9.910+0	-1.073+2	-6.653-3	-3.850-3	-8.720-3	9.242-2	5.114-3	-1.035+1	-7.566+1	3.776-3	6.844+0	-4.725+2	5.970-3	-1.260+0	-2.431+2	4
	F_y	-1.016+0	1.012+0	1.071+2	1.185+2	3.353+3	-5.252-5	-7.031-5	-8.065-4	-9.911-1	1.001-2	2.245+2	5.479+3	8.035-4	-9.965+1	2.906+3	-8.760-4	2.389+2	5.648+3	5
	F_z	-8.763-2	-9.284-2	-9.916+0	-1.877+3	-1.184+2	-6.389-3	-3.697-3	-8.689-3	9.202-2	-5.709-3	-1.051+1	-8.135+1	-3.872-3	6.988+0	-4.746+2	-6.011-3	1.535+0	2.479+2	1
	M_x	-3.067-1	-3.249-1	-3.481+1	-6.570+3	-4.140+2	-4.513-1	-1.294-2	-3.041-2	3.220-1	-1.198-2	-3.681+1	-2.847+2	-1.355-2	2.445+1	-1.061+3	-2.103-2	-5.374+0	8.678+2	1
	M_y	4.209-1	-6.170-1	6.992+2	-3.785+3	3.911+2	-5.018-2	-6.117-3	-0.000+0	0.000+0	-1.103+0	1.045+2	-1.141+3	-9.247-1	8.973+1	8.309+3	-1.133+0	-9.240+1	2.260+3	9
	M_z	2.750-1	-5.020-1	6.367+3	3.861+2	3.392+2	-4.058-1	1.494-2	3.054-2	-3.234-1	8.494-2	2.653+1	3.707+2	7.257-2	-3.227+1	2.424+3	8.427-2	1.298+1	6.407+2	6
Position 6	F_x	-1.135-1	1.204-1	-1.784+3	6.987+0	3.715+1	-6.666-3	-3.858-3	-8.720-3	0.000+0	1.311-2	-3.628-8	-2.305+4	5.960-3	-9.222-8	6.800+6	1.402-2	-8.996-8	-2.249+6	6
	F_y	-1.014+0	-1.016+0	-3.731+1	2.539+2	3.324+3	-1.219-3	-7.228-4	1.606-3	-9.829-1	1.304-9	2.438+2	1.009+3	1.149-9	-1.079+2	5.393+3	2.072-9	2.537+2	1.039+1	1 2
	F_z	-5.581-2	-5.546-2	6.920+0	-1.908+3	-2.539+2	-6.244-3	-3.613-3	-8.577-3	1.840-1	9.023-9	1.521+1	-5.722+2	3.793-9	9.722+0	-8.170+2	3.201-9	-9.273+0	-5.673+2	1 1
	M_x	-1.953-1	1.941-1	2.435+1	-6.681+3	-8.883+2	-4.538-1	-1.264-2	-3.002-2	6.141-1	3.158-9	-5.571+1	1.862+3	1.327-9	3.402+1	-2.859+3	3.251-9	-3.215+1	-1.985+3	1
	M_y	1.129+0	-9.711-1	6.877+2	1.424+3	-2.183+2	-7.237-2	4.122-3	-0.000+0	-0.000+0	-1.266+0	7.867-7	5.211-5	-8.744-1	-1.664-6	1.128-4	-1.247+0	1.355-6	5.108-5	-8
	M_z	1.903-1	2.671-1	6.408+3	-2.311+2	-8.915-1	-4.026-1	1.273-2	3.054-2	0.000+0	1.892-1	-1.882-8	-1.334-6	1.412-1	6.683-7	-1.036-5	1.913-1	-4.158-8	-1.683-6	1
Position 7	F_x	-1.520-1	9.544-2	1.814+3	1.681+1	1.814+2	-6.613-3	-3.831-3	-8.726-3	-9.242-2	5.114-3	1.035+1	7.566+1	3.776-3	-6.844+0	4.725+2	5.970-3	1.260+0	2.431+2	4 2
	F_y	-9.924-1	1.001+0	1.814+2	1.116+2	3.333+3	-1.279-3	-7.405-4	-8.065-4	-9.914-1	-1.001+2	2.245+2	5.479+3	-8.035-4	-9.965+1	2.906+3	8.760-4	2.389+2	5.645+3	6 6
	F_z	-9.161+2	-8.902-2	1.061+1	-1.893+3	-1.165+2	6.270-3	-3.631+3	-8.689-3	9.202-2	5.709-3	-1.051+1	-8.135+1	3.872-3	5.988+0	-4.746+2	6.011-3	-1.535+0	-2.419+2	4 3
	M_x	-3.312-1	-3.115-1	5.995+1	-6.593+3	-1.080+2	-4.531+1	-1.271-2	-3.041+2	3.220+1	1.998-2	-3.661+1	-2.547+2	1.355-2	2.415+1	-1.061+3	2.103-2	-5.371+0	-8.678+2	1
	M_y	7.867-1	-2.538+1	7.016+2	6.711+3	-5.869+2	-1.409+2	1.143+2	-0.000+0	-0.000+0	-1.106+0	-1.045+2	1.141+3	-9.247-1	-8.973+1	8.309+3	-1.133+0	9.240+1	-2.260+3	-1
	M_z	1.591+1	-3.124+1	6.416+3	-6.720+2	-5.806+2	-4.092+1	1.207-2	3.054-2	3.234-1	8.494-2	-2.653+1	-3.707+2	7.257-2	3.227+1	-2.424+3	8.427-2	1.298+1	-6.407+2	6
Position 8	F_x	-1.874+1	5.918-2	-1.861+3	0.000+0	3.201+2	-6.523+3	-3.775-3	-3.726-3	-1.840+1	-8.387-4	1.770+1	-2.732+2	-1.179+1	-1.335+1	5.693+2	1.177-4	5.917+0	2.082+2	-1 4
	F_y	-9.673-1	-9.836-1	-3.202+2	-1.896+1	3.301+3	-1.302-3	-7.539-4	0.000+0	-9.829-1	-1.691+2	2.141+2	-8.894+2	-2.983+3	9.609+1	-2.365+2	-2.371-3	2.219+2	1.208+3	-2
	F_z	1.236-1	-1.236+1	0.000+0	-1.897+3	1.937+1	-6.367-3	-3.684-3	8.726-3	0.000+0	8.839-3	-2.235-8	-3.552+6	9.056-3	-3.168-7	1.022-5	9.541-3	-2.511-7	5.765-6	9 0
	M_x	1.327-	1.326-1	0.000+0	-6.640+3	6.780+1	-4.512-1	-1.289-2	-3.054-2	0.000+0	3.093-2	-7.824-8	-1.243-5	5.169-2	-1.109-6	3.577-5	3.340-2	-8.802-7	2.017-5	3 1
	M_y	3.331+1	3.905-1	-7.258+2	1.114+4	3.978+1	4.281-2	2.466-2	-0.000+0	-0.000+0	-9.977-1	-1.417+2	4.800+3	-1.013+0	-1.805+2	1.218+4	-1.014+0	1.078+2	-5.623+3	-1
	M_z	6.560-1	-2.081-1	6.514+3	0.000+0	-1.121+3	1.091-1	1.321-2	3.054-2	6.441-1	2.935-3	-6.196+1	9.531+2	5.178-1	4.673+1	-1.992+3	4.121-4	-2.071+1	-7.239+2	5
Position 9	F_x	1.680+1	9.478-2	1.814+3	-1.684+1	1.316+2	-6.623-3	-3.833+3	-8.726-3	-9.242+2	4.521-3	9.456+0	-3.310+2	-3.565-3	-6.718+0	2.235+2	-4.773-3	1.891+0	8.145+1	-1
	F_y	-9.639+1	-9.776-1	-1.813+2	1.545+2	3.332+3	-1.026-4	-5.937-5	8.065-4	-9.914+1	-8.141+3	2.076+2	-4.685+3	-1.492+3	-8.817+1	-2.389+3	3.922+4	2.034+2	-4.758+3	-1 1
	F_z	-1.479-1	-1.557-1	-1.684+1	1.890+3	1.510+2	-6.401-3	-3.706-3	-8.689-3	-9.202-2	4.157-3	9.223+0	-3.217+2	3.527-3	6.443+0	2.273+2	1.861-3	1.741+0	8.411+1	1 7
	M_x	-5.246-1	-5.451+1	-5.805+1	8.619+3	5.413+2	-4.544-1	-1.297-2	-3.041-2	-3.220-1	1.455-2	3.228+1	-1.136+3	1.234+2	-2.257+1	7.956+2	1.701+2	8.094+0	2.943+2	1
	M_y	-4.375+1	6.028-1	-7.046+2	6.500+3	6.482+2	6.486-2	1.443-2	-0.000+0	-0.000+0	-9.050-1	-8.326+1	1.333+3	-1.078+0	-9.538+1	5.874+3	-9.051-1	7.220+1	-4.311+3	-1 1
	M_z	5.474-1	-2.512+1	6.245+3	6.623+2	-5.755+2	-4.046+1	1.475-2	3.054-2	3.234-1	-6.817-2	-4.082+1	1.560+3	-8.760-2	1.400+1	-2.374+2	-6.725-2	7.762-2	-6.840+2	-8

Figure 9-7. Influence Coefficients for Flight Loads at Gimbal Bearing-to Vehicle Interface and Inlet Line Load Point for Maximum Gimbal Positions

	CASE II GIMBAL INTERFACE							CASE I						CASE II					
	OXIDIZER INLET LINE			FUEL INLET LINE				OXIDIZER LINE LOAD POINT			FUEL LINE LOAD POINT			OXIDIZER LINE LOAD POINT			FUEL LINE LOAD POINT		
	TQ_I	P_I	C_I	TQ_F	P_F	C_F	M_J	TQ_I	P_I	C_I	TQ_F	P_F	C_I	TQ_I	P_I	C_I	TQ_F	P_F	C_F
0.0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	--	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	-0.000+0	0.000+0	0.000+0	0.000+0	0.000+0
.2	0.000+0	2.102+2	1.032+3	0.000+0	-9.592+1	-6.547+2	--	0.000+0	-6.199+1	2.937+2	0.000+0	6.199+1	-2.620+2	0.000+0	-6.199+1	2.937+2	0.000+0	-6.199+1	-2.620+2
2	0.000+0	-6.585+0	2.767+0	0.000+0	6.607+0	3.387+2	--	0.000+0	6.585+0	-2.767+2	0.000+0	6.607+0	-3.387+2	0.000+0	6.585+0	2.767+2	0.000+0	6.607+0	3.387+2
.3	0.000+0	-2.301+1	9.686+2	0.000+0	-2.314+1	1.185+3	0.03936	0.000+0	7.200+0	-2.529+3	0.000+0	2.623+0	-3.638+3	0.000+0	2.260+0	2.529+3	0.000+0	2.623+0	-3.608+3
0.0	-1.000+0	0.000+0	0.000+0	-1.000+0	0.000+0	0.000+0	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.000+0	0.1600	6.526-2	0.000+0	0.000+0	6.526-2	0.000+0	0.000+0	-6.526-2	0.000+0	0.000+0	-6.526-2	0.000+0	0.000+0
0.0	-8.235-3	0.000+0	0.000+0	1.007-2	0.000+0	0.000+0	--	7.608-3	0.000+0	0.000+0	8.214-3	0.000+0	0.000+0	8.235-3	0.000+0	0.000+0	1.007-2	0.000+0	0.000+0
3	0.000+0	1.936+2	-8.021+3	0.000+0	8.141+1	4.166+3	--	-0.000+0	6.199+1	2.508+3	0.000+0	-6.199+1	-2.720+3	0.000+0	-6.199+1	2.508+3	0.000+0	6.199+1	-2.720+3
.2	0.000+0	7.575+0	-2.178+2	0.000+0	1.149+1	1.812+2	--	-0.000+0	-9.068+0	4.511+2	0.000+0	5.625+0	-4.611+2	0.000+0	-3.479+0	6.279+1	0.000+0	4.586+0	-5.175+2
.2	0.000+0	2.651+1	-7.623+2	0.000+0	-1.024+1	6.241+2	0.03936	0.000+0	-9.617+0	2.572+3	-0.000+0	-1.559+1	-1.106+3	0.000+0	-8.275+0	3.873+2	0.000+0	1.028+0	-1.226+3
0.0	-8.262+1	0.000+0	0.000+0	1.211+0	0.000+0	0.000+0	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
0.0	-1.246+1	0.000+0	0.000+0	1.895-1	0.000+0	0.000+0	0.1600	3.743-2	0.000+0	0.000+0	-9.211-2	0.000+0	0.000+0	1.797-2	0.000+0	0.000+0	-1.035-2	0.000+0	0.000+0
.2	-4.773-3	1.891+0	-8.114+1	-1.721-3	-7.496+0	-2.085+2	--	4.331-3	6.812+0	2.714+2	3.538-3	-4.070+0	2.938+2	4.810-3	1.074+1	1.257+2	4.716-3	3.336+0	3.159+2
.3	-3.922+1	2.034+2	-1.758+3	1.310+3	-8.847+1	-2.420+3	--	-0.000+0	-6.199+1	1.401+3	0.000+0	6.199+1	-1.497+3	0.000+0	-6.199+1	1.401+3	0.000+0	-6.199+1	-1.497+3
.2	4.001-3	1.741+0	8.411+1	-1.725-3	-7.220+0	2.125+2	-	4.334-3	-6.812+0	2.711+2	3.538-3	1.070+0	-2.938+2	1.810-3	1.074+1	1.257+2	4.716-3	3.336+0	-3.159+2
.2	-1.701-2	6.094+0	2.943+2	1.653-2	-2.527+1	7.439+2	0.03936	-4.028-2	-5.369+0	2.051+3	5.840-2	2.739-1	-2.899+3	2.959-2	-3.317+0	6.855+2	5.737-2	-4.352-1	-2.762+3
3	-9.051+1	-7.220+1	1.311+3	-1.104+0	1.114+2	-5.576+3	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
2	-6.725-2	-7.762-2	6.850+2	-8.591+2	-1.589+1	2.125+2	0.1600	4.028-2	-5.369+0	2.051+3	-5.840+2	2.739-1	-2.899+3	-2.959-2	3.317+0	-6.855+2	-5.737-2	-4.352-1	-2.762+3
.2	-7.177-4	-5.917+0	2.082+2	1.479-4	1.333+1	-5.093+2	--	1.586-	1.159+1	2.518+2	-5.427-3	5.370+0	3.923+2	-7.710-9	4.153+1	2.135+2	6.747-9	4.333+0	6.021+2
.2	2.374-3	2.219+2	1.208+3	2.983+3	-9.609+1	-3.365+3	--	-0.000+0	-6.199+1	2.937+3	0.000+0	-6.199+1	-2.620+2	0.000+0	-6.199+1	2.937+2	0.000+0	6.199+1	2.620+2
0.0	-9.543-3	1.005-7	-2.306+6	-9.036-3	1.267-7	-4.088+6	.	3.839-3	8.701-8	-1.876+6	7.551-3	4.091-8	4.414+6	9.543-3	3.094-9	1.811-6	9.036-3	-1.228-8	1.468-6
-5	-3.340-2	3.520-7	-8.061+6	3.169-2	4.436-7	-1.401-5	0.03936	-6.523-2	6.590-8	-2.393+5	9.778-2	1.017-8	3.513-5	5.052-2	4.001-8	1.257+6	9.615-2	1.915-8	3.355-5
1	-1.014+0	1.078+2	5.623+3	-1.013+0	1.805+2	-1.218+4	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
.3	4.121-4	2.071+1	7.289+2	5.177-4	-1.673+1	1.992+3	0.1600	4.860-9	-8.857+0	3.212+3	7.285-9	-1.415+0	-4.505+3	3.761-9	-5.373+0	-1.242+3	7.196-9	-2.570+0	-4.504+3
.2	5.970-3	-1.260+0	2.431+2	4.259-3	6.929+0	-4.611+2	--	-5.404-3	7.492+0	4.030+0	-3.818-3	-2.609+0	3.556+2	-5.983-3	-1.221+0	1.845+2	-4.300-3	-1.932+0	3.249+2
.3	-8.760-4	2.389+2	5.648+3	6.881-4	-9.965+1	2.905+3	--	-0.000+0	-6.199+1	1.469+3	0.000+0	-6.199+1	1.572+3	0.000+0	-6.199+1	-1.469+3	0.000+0	-6.199+1	1.572+3
2	6.911-3	-1.535+0	-2.479+2	-4.353-3	7.072+0	1.631+2	--	5.404-3	7.492+0	4.030+0	3.818-3	-2.609+0	3.556+2	5.983-3	1.221+0	1.845+2	4.300-3	-1.932+0	3.249+2
.3	-2.103-2	-5.374+0	-8.678+2	-1.523-2	2.475+1	1.521+3	0.03936	-4.800-2	4.385+0	-2.017+3	5.257-2	1.458+0	2.475+3	4.004-2	1.796+0	1.219+3	4.917-2	2.060+0	2.210+3
.3	-1.139+0	-9.240+1	2.266+3	-9.110+1	9.151+1	-8.072+3	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
3	8.427-2	1.298+1	6.407+2	6.991-2	-3.274+1	2.303+3	0.1600	-4.800-2	-4.385+0	2.017+3	5.257-2	1.458+0	-2.475+3	1.004-2	-1.796+0	-1.219+3	4.917-2	-2.060+0	-2.210+3
6	1.402-2	-8.395-8	-2.249+6	6.891-3	9.987-8	7.256+6	--	-1.113-2	-7.615-8	-2.151-6	-5.900-3	1.650-8	-3.373+6	-1.102-2	-3.025-8	2.615-6	6.893-3	1.230-8	-3.290-6
3	2.072-9	2.136+2	1.039+3	1.282-9	-1.073+2	5.406+3	--	-0.000+0	-6.199+1	-2.508+3	0.000+0	-6.199+1	2.808+3	0.000+0	-6.199+1	-2.508+3	0.000+0	-6.199+1	2.808+3
.2	9.299-9	-9.273+0	-5.673+2	4.135-9	1.071+1	-8.773+2	--	-9.771-9	1.027+1	2.881+2	4.110-9	-2.215+0	4.536+2	-1.014-9	4.060+0	3.509+2	-5.136-9	-1.451+0	4.416+2
.3	3.251-9	-3.245+1	-1.985+3	1.552-9	3.712+1	-3.070+3	0.03936	3.400-9	6.740+0	-2.013+3	-5.051-9	3.900+0	2.889+3	-1.330-9	5.109+0	2.144+2	-5.165-9	4.893+0	2.806+3
-4	-1.297+0	1.935-6	5.158+3	-8.562-1	-2.017-6	1.522+4	--	1.000+0	0.000+0	0.000+0	1.000+0	-0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
)	1.911+1	4.758-8	1.689+5	[illegible]	7.219-7	5.391+5	0.1600	1.564+2	5.022+8	1.522+5	5.257+2	1.178+0	-2.475+3	1.786+2	3.806-8	1.605+6	6.932+2	3.650-8	2.091+5
2	5.910-3	1.260+0	2.431+2	4.259-3	-6.924+0	1.611+2	--	-5.404-3	-7.492+0	4.030+0	-3.818-3	2.609+0	-3.556+2	-5.983-3	1.221+0	1.845+2	-4.300-3	1.932+0	-3.249+2
3	8.760-1	2.389+2	5.648+3	-6.864-1	-9.965+1	2.905+3	--	-0.000+0	-6.199+1	-1.469+3	0.000+0	6.199+1	1.572+3	0.000+0	-6.199+1	-1.469+3	0.000+0	6.199+1	1.572+3
.2	6.011-3	1.535+0	-2.419+2	4.353-3	7.072+0	-4.631+2	--	-5.404-3	7.492+0	4.030+0	-3.818-3	-2.609+0	3.556+2	-5.983-3	1.221+0	1.845+2	-4.300-3	1.932+0	3.210+2
.3	2.103-2	5.374+0	-8.678+2	1.521-2	2.475+1	-1.621+3	0.03936	4.800-2	4.385+0	-2.017+3	-5.257-2	1.458+0	2.475+3	-4.004-2	1.796+0	1.219+3	4.917-2	2.060+0	2.210+3
3	-1.139+0	9.240+1	-2.266+3	9.110+1	9.151+1	8.072+3	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
3	8.427-2	-1.238+1	-6.407+2	6.991-2	3.271+1	-2.363+3	0.1600	1.800-2	1.385+0	-2.017+3	5.257-2	1.458+0	2.475+3	1.001-2	1.796+0	1.219+3	4.917-2	2.060+0	2.210+3
2	-1.177-4	5.917+0	2.082+2	1.479-4	-1.333+1	5.093+2	--	1.636-	1.159+1	2.518+2	1.586-4	4.333+0	-6.021+2	1.777-9	-4.153+1	-2.135+2	1.686-9	4.333+0	-6.021+2
.2	-2.374-3	2.219+2	-1.208+3	-2.983-3	-9.603+1	-2.365+2	--	-0.000+0	-6.199+1	2.937+2	0.000+0	6.199+1	-2.620+2	0.000+0	-6.199+1	2.937+2	0.000+0	-6.199+1	-2.620+2
5	9.531-3	-2.414-7	5.705+5	9.050-3	-3.168-7	1.022+5	--	8.839-3	-2.177-7	4.690+6	-9.036-3	8.072-8	-1.122+5	-9.513-3	-7.735-9	4.536+6	-9.036-3	8.072-8	-1.122+5
5	3.340-2	-8.802-7	2.017+5	3.169-2	-1.109+6	3.577+5	0.03936	6.523-2	-1.047-7	5.983-5	-9.615-2	-4.788-8	-8.389-5	5.052-2	-1.000-7	2.314-5	-9.615-2	-4.788-8	-8.389-5
4	-1.014+0	1.078+2	-5.623+3	-1.013+0	-1.805+2	1.218+4	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
.3	1.121-4	-2.071+1	-7.289+2	5.178-4	4.673+1	-1.992+3	0.1600	1.215-9	8.857+0	-3.212+3	1.796-9	2.570+0	4.501+3	-9.311-9	5.373+0	1.242+3	-1.796-9	2.570+0	4.504+3
.2	-4.773-3	1.891+0	8.114+1	-1.721-3	-7.496+0	2.085+2	--	4.131-3	6.812+0	2.714+2	3.538-3	4.070+0	-2.938+2	4.810-3	-1.074+1	-1.257+2	4.716-3	3.336+0	-3.159+2
.3	3.922-1	2.034+2	-1.758+3	1.310+3	8.847+1	-2.420+3	--	-0.000+0	6.199+1	1.401+3	0.000+0	-6.199+1	-1.497+3	0.000+0	-6.199+1	1.401+3	0.000+0	6.199+1	1.497+3
2	4.001-3	1.741+0	8.411+1	4.725-3	-7.220+0	2.125+2	-	-4.334-3	-6.812+0	2.714+2	-3.538-3	4.070+0	-2.938+2	-1.817-3	-1.074+1	-1.257+2	4.716-3	3.336+0	-3.159+2
.2	1.701-2	6.094+0	2.943+2	1.653-2	-2.527+1	7.439+2	0.03936	4.028-2	-5.369+0	2.054+3	-5.840-2	-2.739-1	-2.899+3	[illegible]	-3.317+0	-6.855+2	-5.737-2	-4.352-1	-2.762+3
3	-9.051+1	7.229+1	-1.311+3	-1.104+0	-1.114+2	5.576+3	--	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0	1.000+0	0.000+0	0.000+0
2	-6.725-2	7.762-2	-6.840+2	-8.591-2	1.589+1	-2.125+2	0.1600	4.028-2	5.369+0	-2.054+3	-5.840-2	2.739-1	2.899+3	-2.959-2	3.317+0	6.855+2	-5.737-2	4.352-1	2.762+3

Particular Values for Inlet Variables

P_L, P_F, TQ_L, TQ_{LI}, TQ_{FI}, C_L, and C_F

for Each Engine Gimbal Position

P_L = [(Maximum operating plus surge pressure) ±4.0 psi] (limit load factor)

P_F = [(Maximum operating plus surge pressure) ±4.0 psi] (limit load factor)

$TQ_{L\ MAX} = 16,600 + E + |F + 64.5P_L$ in-lb

$TQ_{L\ MIN} = -16,600 + E - |F + 64.5P_L$ in-lb

$TQ_{LI\ MAX} = 16,700 + E + |F + 64.5P_L$ in-lb

$TQ_{LI\ MIN} = -16,500 + E - |F + 64.5P_L$ in-lb

$TQ_{F\ MAX} = 15,600 + E + |G + 64.5P_F$ in-lb

$TQ_{F\ MIN} = -13,900 + E - |G + 64.5P_F$ in-lb

$TQ_{FI\ MAX} = 17,200 + E + |G + 64.5P_F$ in-lb

$TQ_{FI\ MIN} = -15,600 + E - |G + 64.5P_F$ in-lb

Engine Gimbal Position	E (in-lb)	F (in-lb)	G (in-lb)	C_L	C_F
1	0	0	0	1	1
2	0	4580	-5070	1	1
3	-2760	2280	-2540	1	1
4	0	0	0	1	1
5	+2760	-2280	2540	1	1
6	0	-4580	5070	1	1
7	-2760	-2280	2540	1	1
8	0	0	0	1	1
9	+2760	2280	-2540	1	1

Figure 9-8. Values for Inlet Variables

9-10. Special information is provided for nongimbaled engines where the vehicle ducts are mounted directly to the turbopump inlet flanges.

9-11. The influence coefficients of the nine gimbal positions for the maximum gimbal angles are given in figure 9-7. Two sets of influence coefficients for the inlet line variables are tabulated because of the large variation in their resultant loads from different combinations of misalinement. The Case I coefficients are presented so that the largest loads at the inlet line interfaces, with compatible loads at the gimbal, can be calculated. The Case II coefficients are presented so that the largest loads at the gimbal interface, with compatible loads at the inlet line interfaces, can be calculated. The magnitudes of the inlet variables for the nine gimbal positions are provided in figure 9-8.

9-12. The coefficients are calculated using a limit coefficient of friction μ equal to 0.16 for the gimbal bearing surfaces. This same set of influence coefficients can be used with other values of μ, such as μ_1, by modifying the KF_N and M_y variables to $\frac{1}{.16} KF_N$ and $\frac{1}{.16} M_y$.

NOTE

MAX = .12, using a 1.3 limit load factor yields limitμ= 1.3 (.12) = .16.

9-13. The influence coefficients in figure 9-7 are expressed as a decimal number followed by the sign and magnitude of the exponential power of ten to which this number must be raised. For example, an influence coefficient with a value of 285.6 would be equal to 2.856×10^2 and be expressed in these tables as 2.856+2. Similarly, a value of 0.0026 would be expressed as 2.600-3.

9-14. It should be noted that M_y, the moment on the vehicle Y axis at the gimbal mating surface, is used as a final variable for calculating the perturbation on the M_x and M_z loads due to the friction moment resulting from the torsion load.

9-15. The resultant loads at the gimbal-to-vehicle interface that are calculated from these influence coefficients consider only the effects of the variables listed in figure 9-8. The additional resultant loads at the gimbal-to-vehicle interface from the heat shield, the interface connection system, the aerodynamic moments, and/or any other additional loads must be handled separately as a perturbation on this analysis.

9-16. A sample problem is included to demonstrate the use of the influence coefficients. The M_x and M_y flight loads at the gimbal and inlet line interfaces for gimbal Position 2 are calculated for the largest loads on the gimbal; this implies that Case II of the inlet line influence coefficients must be used.

9-17. LIST OF NOMENCLATURE. Figure 9-9 lists the nomenclature used in the sample problem.

NOTE

See figure 9-8 for the particular values of the inlet line variables at each gimbal position.

9-18. The effective pressures of the lines P_L and P_F include the actual line pressures plus an effective pressure, ±4 psi, that accounts for the axial force on the turbopump and vehicle necessary to overcome the friction load when the line is extended or compressed.

9-19. The values of E, F, and G are dependent on gimbal position and are tabulated in figure 9-8. The first term of each equation is dependent on various load deflections of the engine and vehicle twisting the line. The second term, E, accounts for the twisting of the engine with respect to the vehicle from gimbaling. The last term, an absolute magnitude quantity, is the torsional load necessary to overcome the frictional moment which is caused by the axial deflection load, G and F terms, and the pressurization load, P_L and P_F terms, carried in the center-ring section that houses the torsion bellows. A 1.3 limit load factor (figure 9-11) has been included in the listed values for the various torques.

9-20. SAMPLE PROBLEM. The sample problem may not use current influence coefficients or particular values for inlet variables since these values are updated when design changes dictate; however, the procedure remains unchanged. To illustrate the use of influence coefficients, the maximum M_y and its compatible value of M_x for gimbal Position 2 are calculated for flight-loading conditions. The input variables are:

a. Maximum actuator force = ±42,000 lb.

b. Maximum lateral acceleration = 1.0 G.

c. Maximum longitudinal acceleration compatible with 1.0 G lateral = 2.5 G.

d. Maximum thrust (5.50 mixture ratio) = 230,000 lb.

F_{1A}	(lb)	The force applied to the engine from Actuator 1. Tension in the actuator is a positive force.
F_{2A}	(lb)	The force applied to the engine from Actuator 2. Tension in the actuator is a positive force.
A_{LAT}COS Ø	(G's)	The projection of the vehicle lateral acceleration on the XY plane of the vehicle. The positive direction is shown in figure 9-10.
A_{LAT}SIN Ø	(G's)	The projection of the vehicle lateral acceleration on the YZ plane of the vehicle. The positive direction is shown in figure 9-10.
Ø	(deg)	The angle between the lateral acceleration of the vehicle and the vehicle XY plane (figure 9-10). At Ø = 0, A_{LAT} is in this XY plane in the direction of the positive X axis. Positive Ø is a clockwise rotation looking forward along the vehicle Y axis.
A_{LONG}	(G's)	The vehicle longitudinal acceleration, parallel to the vehicle Y axis. The positive direction is shown in figure 9-10.
F_N	(lb)	The approximate resultant force on the gimbal due to a specific set of loads on the engine is given by $F_N = T + F_{1A} + F_{2A}$. KF_N is used to calculate the friction moment of the engine gimbal due to resultant forces across it. Since the friction moment can add to or subtract from the applied loads on the gimbal, the product of the coefficients times KF_N can have two sets of values. Compatible signs for one set of coefficients are listed as part of the coefficients. The other compatible set of values is obtained by use of the opposite sign for each term. The choice of which set to use is dependent on the desired effect on the gimbal.
K	$\frac{\text{(in.)}}{\text{in.}}$	A constant dependent on the geometry of the gimbal. K = 1.0 for flight load conditions or any load conditions when F_N is positive. K = 0.518 for dry gimbaling conditions or any load condition when F_N is negative.
T_{Δ}	(lb)	The engine thrust, T, is positive as shown in figure 9-10. The thrust times this set of coefficients calculates the effect of the thrust offset or misalinement, Δ, of the engine on the gimbal loads. Since the effect of the misalinement can add to or subtract from the applied loads on the gimbal, these coefficients have two sets of values and are treated similarly to the KF_N coefficient.

Figure 9-9. List of Nomenclature (Sheet 1 of 3)

T_θ	(lb)	The engine thrust, T, is positive as shown in figure 9-10. The thrust times this set of coefficients calculates the effect of the angular misalinement, θ, of the engine. Since the effect of the misalinement can add to or subtract from the applied loads on the gimbal, these coefficients have two sets of values and are treated similarly to the KF_N coefficient.
T_α	(lb)	The engine thrust, T, is positive as shown in figure 9-10. The thrust times this set of coefficients calculates the thrust loads on the vehicle. The coefficients for various positions include the effects of the sine or cosine of the gimbal angle.
TQ_L	(in-lb)	The torsion load from the oxidizer inlet line on the engine.
TQ_{LI}	(in-lb)	The torsion load from the oxidizer inlet line to the oxidizer inlet line interface.
P_L	(psi)	The effective pressure in the oxidizer inlet line. It includes the pressure in the line plus an additional pressure that accounts for the axial force on the turbopump and vehicle necessary to overcome the friction load from axial movement of the line.
C_L	$\left(\frac{lb/in}{lb/in}\right)$	A constant dependent on the oxidizer inlet line spring rate.
TQ_F	(in-lb)	The torsion load from the fuel inlet line on the engine.
TQ_{FI}	(in-lb)	The torsion load from the fuel inlet line on the inlet line interface.
P_F	(psi)	The effective pressure in the fuel inlet line. It includes the pressure in the line plus an additional pressure that accounts for the axial force on the turbopump and vehicle necessary to overcome the friction load from axial movement of the line.
C_F	$\left(\frac{lb/in}{lb/in}\right)$	A constant dependent on the fuel inlet line spring rate.
E	(in-lb)	The torsion load on the inlet lines caused by twisting the engine with respect to the vehicle when gimbaling.

Figure 9-9. List of Nomenclature (Sheet 2 of 3)

F, G	(in-lb)	The frictional torsion load on the inlet lines caused by the axial deflection of the lines.
F_x, F_y, F_z	(lb)	The resultant applied forces and moments on the vehicle at the gimbal and inlet line interfaces in a vehicle coordinate system that is parallel to the engine coordinate system when the engine has a zero-degree gimbal angle.
M_x, M_y, M_z	(in-lb)	
μ	$\left(\frac{lb}{lb}\right)$	Coefficient of friction.

NOTE

Do not use Case I or Case II influence coefficients simultaneously.

Case I Influence Coefficients	This set of influence coefficients is used to obtain the largest loads at the inlet line load point with compatible loads at the gimbal interface.
Case II Influence Coefficients	This set of influence coefficients is used to obtain the largest loads at the gimbal interface with compatible loads at the inlet line load point.
Gimbal Interface	The plane between the gimbal and the vehicle structure if the shear keys are ignored.
Oxidizer Inlet Line Interface	The plane between the oxidizer inlet line flange and the vehicle seal and flange.
Fuel Inlet Line Interface	The plane between the fuel inlet line flange and the vehicle seal and flange.
Inlet Line Load Point	A point on the inlet duct centerline 2 inches from the inlet line interface on the engine side of the inlet line interface.

Figure 9-9. List of Nomenclature (Sheet 3 of 3)

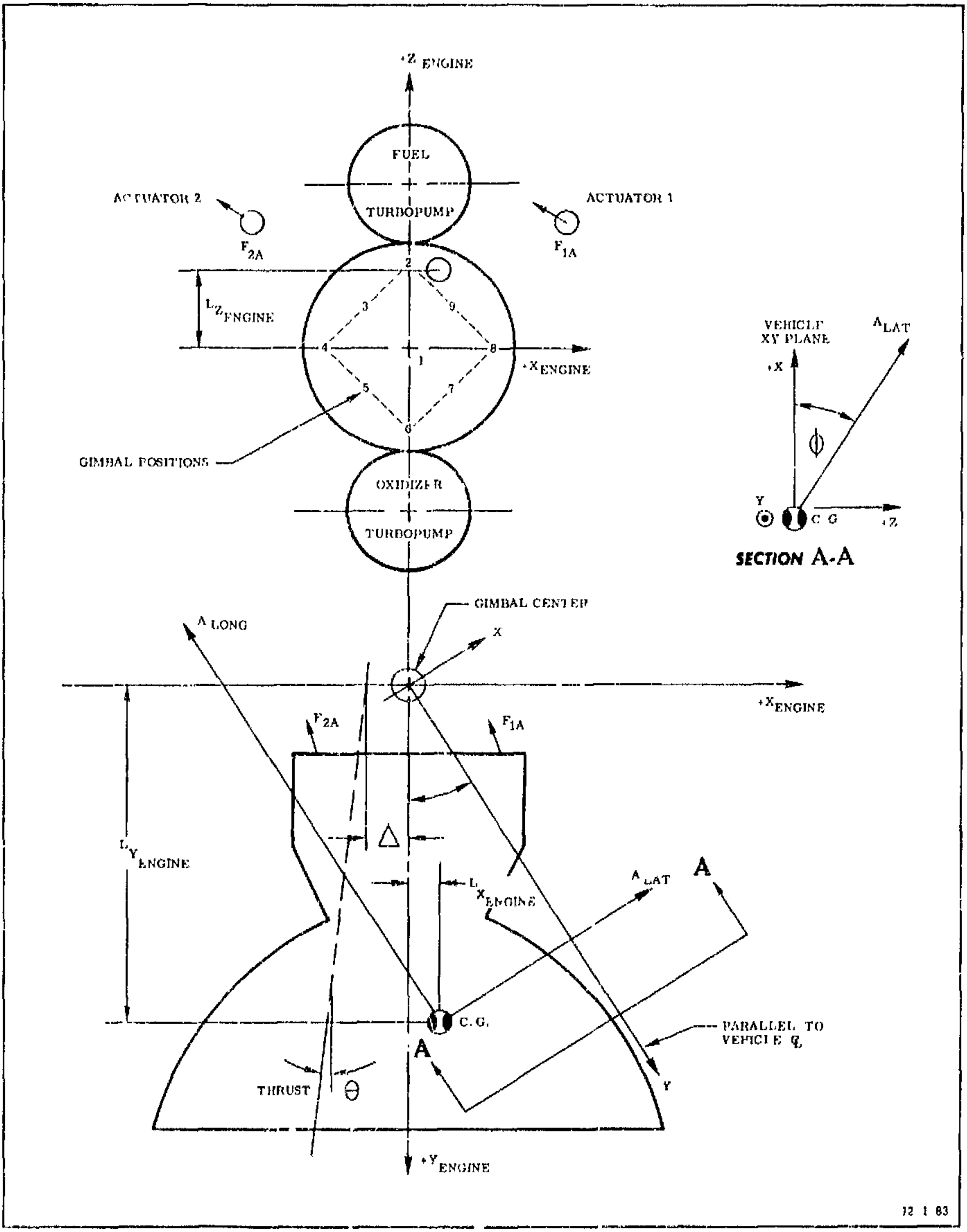


Figure 9-10. Nomenclature for Loads

Design Loads	Limit Load Factors
Fluid Pressure	1.2 (maximum operating pressure plus surge pressure)
Engine Thrust	1.05 (using maximum thrust)
Acceleration	1.0 (engine forward acceleration)
	1.0 (engine lateral acceleration)
Actuator Loads	1.1 (using maximum actuator loads)
Duct Misalinements	1.3 (using calculated loads)

Figure 9-11. Limit Load Factors Used in Load Calculations

9-21. The additional information necessary to obtain the inlet line loads is listed in figure 9-8. The limit loads for the variables are computed from the limit load factors listed in figure 9-11.

In general, limit load = (limit load factor) (maximum or specified load). Using the 1.1 limit load factor for actuator loads, the two actuator limit loads are:

$$F_{1A} = (1.1)\ (\pm 42{,}000\ \text{lb}) = \pm 46{,}200\ \text{lb}$$

$$F_{2A} = (1.1)\ (\pm 42{,}000\ \text{lb}) = \pm 46{,}200\ \text{lb}$$

To determine $A_{LAT}\text{COS}\ Ø$ and $A_{LAT}\text{SIN}\ Ø$, the angle Ø must be determined. The specific angle will be the value that maximizes the sum of the $A_{LAT}\text{SIN}\ Ø$ and $A_{LAT}\text{COS}\ Ø$ terms for the load parameter being maximized, M_y.

In general, load = ... $+A_{LAT}\text{COS}\ Ø\ D_{i3} + A_{LAT}\text{SIN}\ Ø\ D_{i4}$ ....., where D_{i3} and D_{i4} are the appropriate coefficients.

To maximize the angle Ø, set $\frac{d(\text{load})}{dØ} = 0$

$$\frac{d(\text{load})}{dØ} = -A_{LAT}\text{SIN}\ Ø\ D_{i3} + A_{LAT}\text{COS}\ Ø\ D_{i4} = 0$$

Solving for Ø,

$$\text{TAN}\ Ø = \frac{A_{LAT}D_{i4}}{A_{LAT}D_{i3}}$$

$$Ø = \text{ARC TAN}\ \frac{D_{i4}}{D_{i3}}$$

For the specific case of maximizing the M_y load,

$$Ø = \text{ARC TAN}\ \frac{D_{54}}{D_{53}}\ ; \quad \text{where:}$$

D_{54} = influence coefficient for the M_y load component from $A_{LAT}\text{SIN}\ Ø$

D_{53} = influence coefficient for the M_y load component from $A_{LAT}\text{COS}\ Ø$

from the influence coefficients for gimbal Position 2, M_y load,

$$D_{53} = 3{,}236+2$$

$$D_{54} = 1.532+3$$

$$Ø = \text{ARC TAN}\ \frac{1532.}{323.6} = \text{ARC TAN}\ 4.737$$

$$Ø = 78.10°$$

Hence, using the above information and a 1.0 limit load-factor,

$$A_{LAT}\text{SIN}\ Ø = (1.0)(1.0\ \text{G})\ (0.9781)$$
$$= 0.9784\ \text{G}$$

$$A_{LAT}\text{COS}\ Ø = (1.0)(1.0\ \text{G})(0.2067)$$
$$= 0.2067\ \text{G}$$

Again, using a 1.0 limit-load factor on acceleration, the limit longitudinal acceleration becomes:

$$A_{LONG} = 1.0\ (2.5\ \text{G}) = 2.5\ \text{G}$$

Using a 1.05 limit-load factor on the maximum thrust yields,

$$T = 1.05\ (230{,}000\ \text{lb}) = 241{,}500\ \text{lb}$$

In order to calculate a F_N compatible with the maximization of M_y, the values for F_{1A} and F_{2A} used in calculating this maximum M_y must be used.

From the influence coefficients for Position 2, M_y load, the sign of the coefficients for F_{1A} and F_{2A} are (-) and (+), respectively. Hence, to obtain the largest M_y, the signs of F_{1A} and F_{2A} will be chosen the same as their coefficients:

$$F_{1A} = -46{,}200 \text{ lb}$$

$$F_{2A} = +46{,}200 \text{ lb}$$

With this information, F_N becomes:

$$F_N = T + F_{1A} + F_{2A}$$

$$F_N = 241{,}500 \text{ lb} - 46{,}200 + 46{,}200 \text{ lb}$$

$$F_N = 241{,}500 \text{ lb}$$

For flight loads K = 1, so

$$KF_N = 1.0\ (241{,}500) = 241{,}500 \text{ lb}$$

The values of T_Δ, T_ϕ, and T_α, are all equal to the thrust. The subscript refers only to the effect that causes the loads on the gimbal; so

$$T_\Delta = T_\phi = T_\alpha = 241{,}500 \text{ lb}.$$

9-22. The inlet line pressures consistent with maximum thrust on the engine are the engine operating pressures. Available information indicates that the inlet line surge pressures occur during thrust decay; therefore, surge pressure is zero at maximum thrust. To obtain a range on the pressures, a maximum limit pressure and a minimum limit pressure are calculated. From figure 9-11, the maximum limit pressure is 1.2 times the maximum operating pressure plus surge pressure, and a consistent minimum limit pressure is 1 to 1.2 times the minimum operating pressure.

Since the inlet pressures are dependent on the vehicle pressurization system, the pressures used in this sample problem are approximated.

a. Maximum oxidizer operating pressure = 38.0 psi.

b. Minimum oxidizer operating pressure = 34.0 psi.

c. Maximum fuel operating pressure = 30.5 psi.

d. Minimum fuel operating pressure = 27.5 psi.

From figure 9-8, the inlet line pressures are:

$$P_L = \begin{bmatrix} \text{(maximum operating pressure} \\ \text{plus surge pressure)} \pm 4.0 \text{ psi} \end{bmatrix} \begin{matrix} \text{(limit-} \\ \text{load} \\ \text{factor)} \end{matrix}$$

$$P_F = \begin{bmatrix} \text{(maximum operating pressure} \\ \text{plus surge pressure)} \pm 4.0 \text{ psi} \end{bmatrix} \begin{matrix} \text{(limit-} \\ \text{load} \\ \text{factor)} \end{matrix}$$

$$P_{L\ MAX} = 1.2\ (38.0 + 4.0) = 50.4 \text{ psi}.$$

$$P_{L\ MIN} = (1/1.2)\ (34.0 - 4.0) = 25.0 \text{ psi}.$$

$$P_{F\ MAX} = 1.2\ (30.5 + 4.0) = 41.4 \text{ psi}.$$

$$P_{F\ MIN} = (1/1.2)\ (27.5 - 4.0) = 19.6 \text{ psi}.$$

From figure 9-8, the inlet line torsion loads and spring-rate constants are found:

$$TQ_{L\ MAX} = 11450 + E + |F + 64.5\ P_L| \text{ in-lb}$$

$$TQ_{L\ MIN} = -10400 + E - |F + 64.5\ P_L| \text{ in-lb}$$

$$TQ_{LI\ MAX} = 14050 + E + |F + 64.5\ P_L| \text{ in-lb}$$

$$TQ_{LI\ MIN} = -14000 + E - |F + 64.5\ P_L| \text{ in-lb}$$

$$TQ_{F\ MAX} = 14050 + E + |G + 64.5\ P_F| \text{ in-lb}$$

$$TQ_{F\ MIN} = -13000 + E - |G + 64.5\ P_F| \text{ in-lb}$$

$$TQ_{FI\ MAX} = 22050 + E + |G + 64.5\ P_F| \text{ in-lb}$$

$$TQ_{FI\ MIN} = -21000 + E - |G + 64.5\ P_F| \text{ in-lb}$$

9-23. For Position 2,

$E = 0$

$F = 2850$ in-lb

$G = -3700$ in-lb

Solving for the torques, using the appropriate value of P_L and P_F to give the largest absolute number,

$$TQ_{L\ MAX} = 11450 + 0 + |2850 + 64.5\ (50.4)|$$

$$TQ_{L\ MAX} = 17550 \text{ in-lb.}$$

$$TQ_{L\ MIN} = -10400 + 0 - |2850 + 64.5\ (50.4)|$$

$$TQ_{L\ MIN} = -16500 \text{ in-lb.}$$

$$TQ_{LI\ MAX} = 14050 + 0 + |2850 + 64.5\ (50.4)|$$

$$TQ_{LI\ MAX} = 20150 \text{ in-lb}$$

$$TQ_{LI\ MIN} = -14000 + 0 - |2850 + 64.5\ (50.4)|$$

$$TQ_{LI\ MIN} = -20100 \text{ in-lb}$$

$$TQ_{F\ MAX} = 14050 + 0 + |-3700 + 64.5\ (19.6)|$$

$$TQ_{F\ MAX} = 16486 \text{ in-lb}$$

$$TQ_{F\ MIN} = -13000 + 0 - |-3700 + 64.5\ (19.6)|$$

$$TQ_{F\ MIN} = -15436 \text{ in-lb}$$

$$TQ_{FI\ MAX} = 22050 + 0 + |-3700 + 64.5\ (19.6)|$$

$$TQ_{FI\ MAX} = 24486 \text{ in-lb}$$

$$TQ_{FI\ MIN} = -21000 + 0 - |-3700 + 64.5\ (19.6)|$$

$$TQ_{FI\ MIN} = -23436 \text{ in-lb}$$

9-24. From figure 9-8, the constants C_L and C_F are also obtained: $C_L = C_F = 1$. The detailed calculations of M_x and M_y at the gimbal interface using the input variables and the influence coefficients are listed in figure 9-12. The compatible M_x and M_y moments at the inlet line interface are listed in figure 9-13. The coefficients used for Position 2 of the gimbal pattern and Case II inlet loads for flight conditions.

9-25. The first column of the figures lists the variables. The second column lists the numerical range of the variables that have been calculated. The values listed for KF_N, T_Δ, and M_Y have a ±1 multiplier not previously discussed. This term is inserted in the load range to easily account for the fact that the friction moment and the offset misalinement have two sets of values. One set of values is the sign given in the influence coefficient tables, and the other set is the opposite sign of those listed. This is equivalent to multiplying the variable by (+1) to obtain the first set of coefficients and by (-1) to obtain the second set. The third column lists the loads used for maximizing M_y. When a variable's influence coefficient for a M_y load is negative, the minimum value of the variable is used. When a variable's influence coefficient for the M_y load is zero, the load is independent of the variable. Hence, the value of the variable can be decided by considering one of the other loads (F_x, F_y, F_z, M_x, or M_z) which is dependent on the variable; that is, which has an influence coefficient other than zero. In this manner, a compatible maximization of two variables can be obtained.

9-26. In the specific case calculated, the influence coefficients of the variables for an M_y load have some zero coefficients. In those cases, the variable's influence coefficient for the M_x load is inspected and the magnitude of the variable picked to obtain the largest compatible M_x load. In this example, the magnitude of T_θ, P_L, C_L, P_F, C_F, and M_y variables are dependent on the M_x influence coefficients. All magnitudes in figure 9-13 are consistent with those determined in figure 9-12.

9-27. The maximum M_y is then calculated by multiplying the appropriate load by the M_y influence coefficient and summing up the products. This maximum M_y is then applied as the last variable, No. 16. The M_x load compatible with the maximum M_y is then calculated by multiplying the loads in the third column by the M_x influence coefficients and summing up the products. The remaining load calculations for F_x, F_y, F_z, and M_z can be obtained in a similar manner.

	Variable	Applied Load on Engine		Resultant Applied Load at Vehicle to Gimbal Mating Surface			
		Load Range	Loads for Maximizing M_y	M_x(I.C.)	M_x(in-lb)	M_y(I.C.)	M_y(in-lb)
(1)	F_{1A}	±46,200 lb	-46,200 lb	-6.596-1	30,450.0	-9.861-1	45,558.0
(2)	F_{2A}	+46,200 lb	+46,200 lb	-6.608-1	-30,529.0	1.243+0	57,427.0
(3)	A_{LAT}COSØ	+0.2067 G	+0.2067 G	-2.920+1	-6.0	3,236+2	66.89
(4)	A_{LAT}SINØ	+0.9784 G	+0.9784 G	-6.108+3	-5,976.0	1.532+3	1,498.9
(5)	A_{LONG}	+2.5 G	+2.5 G	8.726+2	2,182.0	2.560+2	640.0
(6)	KF_N	(241,500) (±1)lb	+241,500 lb	-4.552-1	-109,931.0	8.407-2	20,303.0
(7)	T	(241,500) (±1)lb	+241,500 lb	-1.346-2	-3,251.0	2.644-3	638.5
(8)	T_θ	(241,500) (±1)lb	-241,500 lb	-3.002-2	7,250.0	0	0
(9)	T'	241,500 lb	+241,500 lb	-6.441-1	-155,550.0	0	0
<u>Case II Oxidizer Line</u>							
(10)	TQ_L	17,550	-16,500 in-lb	0	0	-8.535-1	14,083.0
(11)	P_L	50.4 25.0	+50.4 psi	3.033-1	15.3	0	0
(12)	C_L	1.0	+1.0	-5.759+2	-757.9	0	0
<u>Case II Fuel Line</u>							
(13)	TQ_F	16,486 -15,436 in-lb	-15,436 in-lb	0	0	-1.202+0	18,554
(14)	P_F	41.4 19.6 psi	19.6 psi	-2.584+1	506.5	0	0
(15)	C_F	1.0	1.0	9.654+1	96.5	0	0
(16)	M_y	(158,769)(±1)	±158,769	.03936	6,252.7	0	0
TOTAL					-260,080.0	compatible max.	158,769 max.

Figure 9-12. Calculations for Maximum M_y With a Compatible Value for M_x at Gimbal Interface With Engine in Position 2

Variable	Load Range	Maximizing Load	Resultant Applied Load at Vehicle to Inlet Line Interface			
			M_x(I.C.)	M_x(in-lb)	M_y(I.C.)	M_y(in-lb)
Case II Oxidizer Line						
(1) TQ_{LI}	20150 -20100 in-lb	-20,100 in-lb	0	0	1.0	-20,100
(2) P_L	50.4 25.0 psi	50.4 psi	-6.858+0	-345.6	0	0
(3) C_L	1.0	1.0	8.596+1	85.9	0	0
TOTAL				-259.7		-20,100
Case II Fuel Line						
(1) TQ_{FI}	21886 -20836 in-lb	-20,836 in-lb	0	0	1.0	-20,836
(2) P_F	41.4 19.6 psi	19.6 psi	-2.381+0	-46.7	0	0
(3) C_F	1.0	1.0	-1,259+3	-1,259.0	0	0
TOTAL				-1,305.7		-20,836

Figure 9-13. Calculations for M_x and M_y Moments Compatible with a Maximum M_y at Gimbal Interface With Engine in Position 2

9-28. PROPELLANT INLET DUCT AND GIMBAL BEARING TOLERANCES AND DEFLECTIONS.

9-29. The propellant inlet duct and gimbal bearing interface clearances and torsional deflections are listed in figure 9-14. The elastic deformation within the gimbal assembly is calculated using gimbal torque values based on the engine as a redundant system with the inlet lines and gimbal-reacting torque loads on the engine. Since Hooke's joint effect and elastic deformation within the gimbal assembly are position dependent, the deflection buildup clearances at the actuator attach point are each broken down into two maximum cases giving compatible values for Hooke's joint effect and elastic deformation. The maximum allowable rotation of the fuel and oxidizer inlet ducts is outlined in figure 9-15.

9-30. GIMBAL BEARING COEFFICIENT OF FRICTION AND FRICTION MOMENT EQUATIONS. Static and dynamic coefficients of friction of the fabroid applied on the gimbal bearing spherical surface (concave surface of bearing seat and body) over a temperature range of -300° to +160° F are defined in figures 9-16 and 9-17. The values were calculated from test data and based on the 2.70-inch spherical seat radius for the gimbal bearing. Combined static and dynamic coefficient of friction of dry-film lubricant RA0112-006 (Rocketdyne) is outlined in figure 9-18. This lubricant is used on torsional load bearing surfaces of the body side panels, shaft, and retainers. Formulas for computing the friction moment of the gimbal under different loads and gimbaling conditions are outlined in paragraphs 9-31 through 9-34.

Torsional Deflection or Clearance Item(a)		Deflection and Clearance Rotation at Actuator Attach Point on Engine (Degrees)	
		Case I	Case II
Torsional Rotation of Gimbal (Hooke's Joint Effect)(b)		0.25	0.00
Chamber Attach Point Deflection		0.10	0.10
Torsional Deflection of Dome		0.10	0.10
Elastic Deformation Within Gimbal Assembly	Flight	0.42	0.60
	Test Stand	0.53	0.77
Manufacturing Tolerances Within Gimbal Assembly(c)		0.22	0.22
Dry-Lubricant Wear			
Body to Shaft		0.05	0.05
Retainer to Shaft		0.03	0.03
Maximum Rotation in One Direction From Installed Position	Flight	1.17	1.10
	Test Stand	1.28	1.27

Torsional Deflection or Clearance Item	Deflection and Clearance Rotation of Propellant Inlet Ducts (Degrees)	
	Oxidizer Duct	Fuel Duct
Torsional Deflection of Propellant Inlet Duct Vehicle Attach Flange	0.20	0.20
Maximum Deflection and Clearance Rotation at Pump Inlet Flange in One Direction From Installed Position	1.30	1.95
Propellant Inlet Duct Torsional Null Position Misalinement	0.20	0.20
Maximum Rotation in One Direction From Duct Torsional Null Position	1.70	2.35

(a) Angle indicated is the maximum predicted value except for (c).

(b) Hooke's joint effect is a function of engine position as is elastic deformation of gimbal assembly. The maximum elastic deformation occurs in a position where Hooke's effect is zero.

(c) Value is based on a selective fit assembly of detailed parts.

NOTE: Case I and Case II maximize the deflection and clearance rotations at the gimbaling positions where Hooke's joint effect has a value of 0.25 degrees and 0.00 degrees respectively.

Figure 9-14. Gimbaling System Torsional Deflections and Clearances

Torsion Bellows (Minimum Rotation from Nominal Position)	±2.10 degrees
Additional Allowable Rotation in Ducts Without Exceeding Allowable Loads on Pumps	±0.32 degree
Total Allowable Rotation	±2.42 degrees

Figure 9-15. Allowable Rotation of Fuel and Oxidizer Inlet Ducts

9-31. The spherical-type gimbal (figure 9-19) has two basic load paths: the torsion load (M_y) is reacted by the shaft, and the forces (axial and lateral) are reacted through the seat when the gimbal has a compressive-load component, as encountered during hot-firing of the engine. When the gimbal has a tensile load component, which occurs during dry gimbaling, the torsion load is reacted similarly to the compressive load, and the forces are reacted by the shaft, the retainers, and the seat.

9-32. Secondary load paths in the gimbal are developed by friction forces resulting in moments about the gimbal center. These friction moments are a function of the gimbal geometry, the coefficient of friction between the sliding surfaces, and the loads across these surfaces. The four surfaces at which the friction moments are generated are:

a. The sockets between the gimbal seat and the gimbal body.

b. The socket between the gimbal body and the spherical surface of the shaft (tensile-load condition only).

c. The journals between the shaft and the retainers.

d. The flat sides of the shaft and the gimbal body.

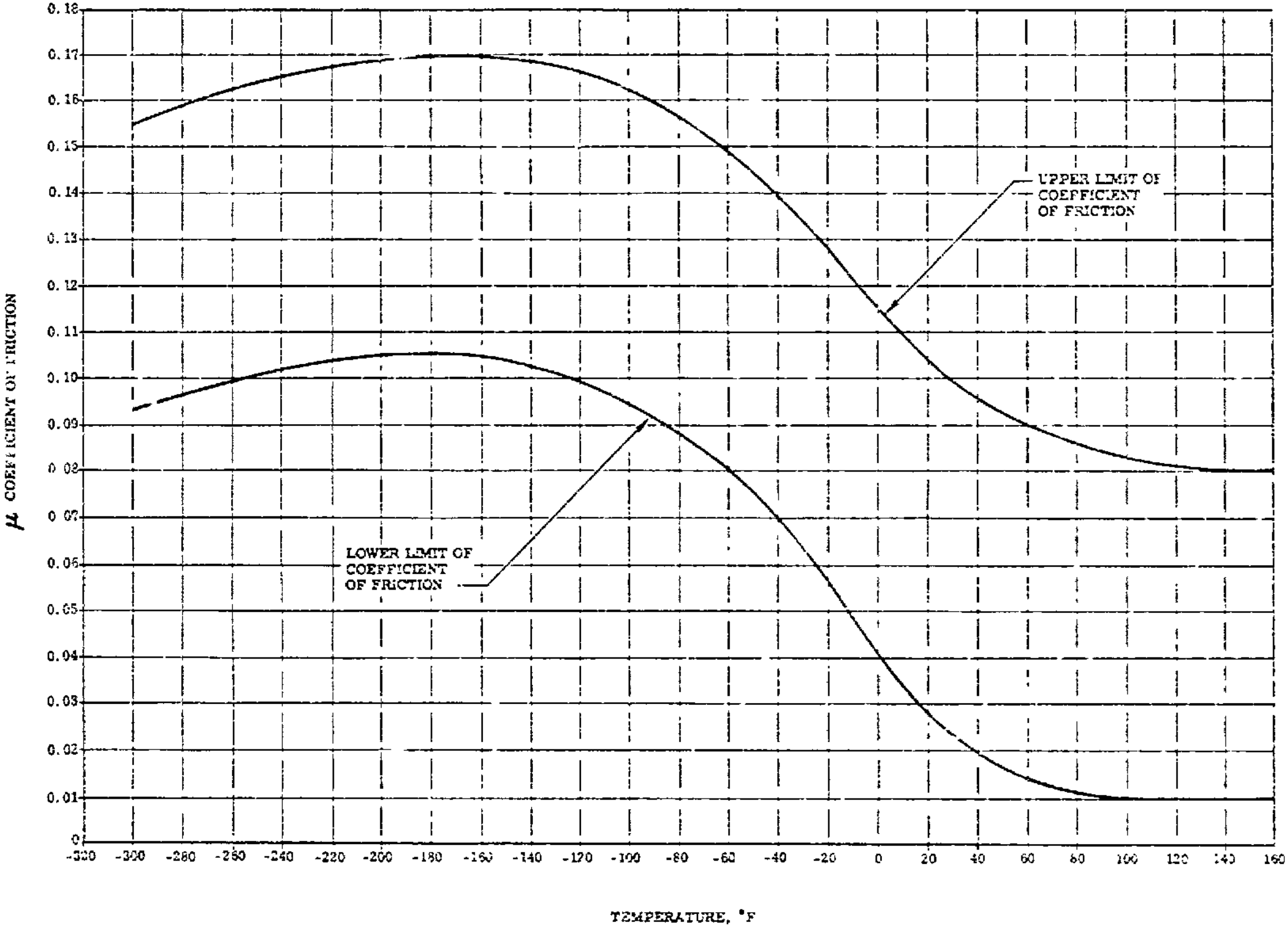
9-33. The following equations are for calculating gimbal-bearing friction moments during hot-firing (compression on the gimbal):

$$M_{x_v} = (\sin \epsilon)\ \mu_3 R_3 \sqrt{(F_x)^2 + (F_y)^2 + (F_z)^2} + k_1\ \mu_2\ \frac{2R_2}{L} \left| M_y + M_x\ (\sin \alpha_m) \right|$$

$$M_{z_v} = (\cos \epsilon)\ \mu_3 R_3 \sqrt{(F_x)^2 + (F_y)^2 + (F_z)^2} + k_2\ \mu_1 \left| M_y + M_x\ (\sin \alpha_m) \right|$$

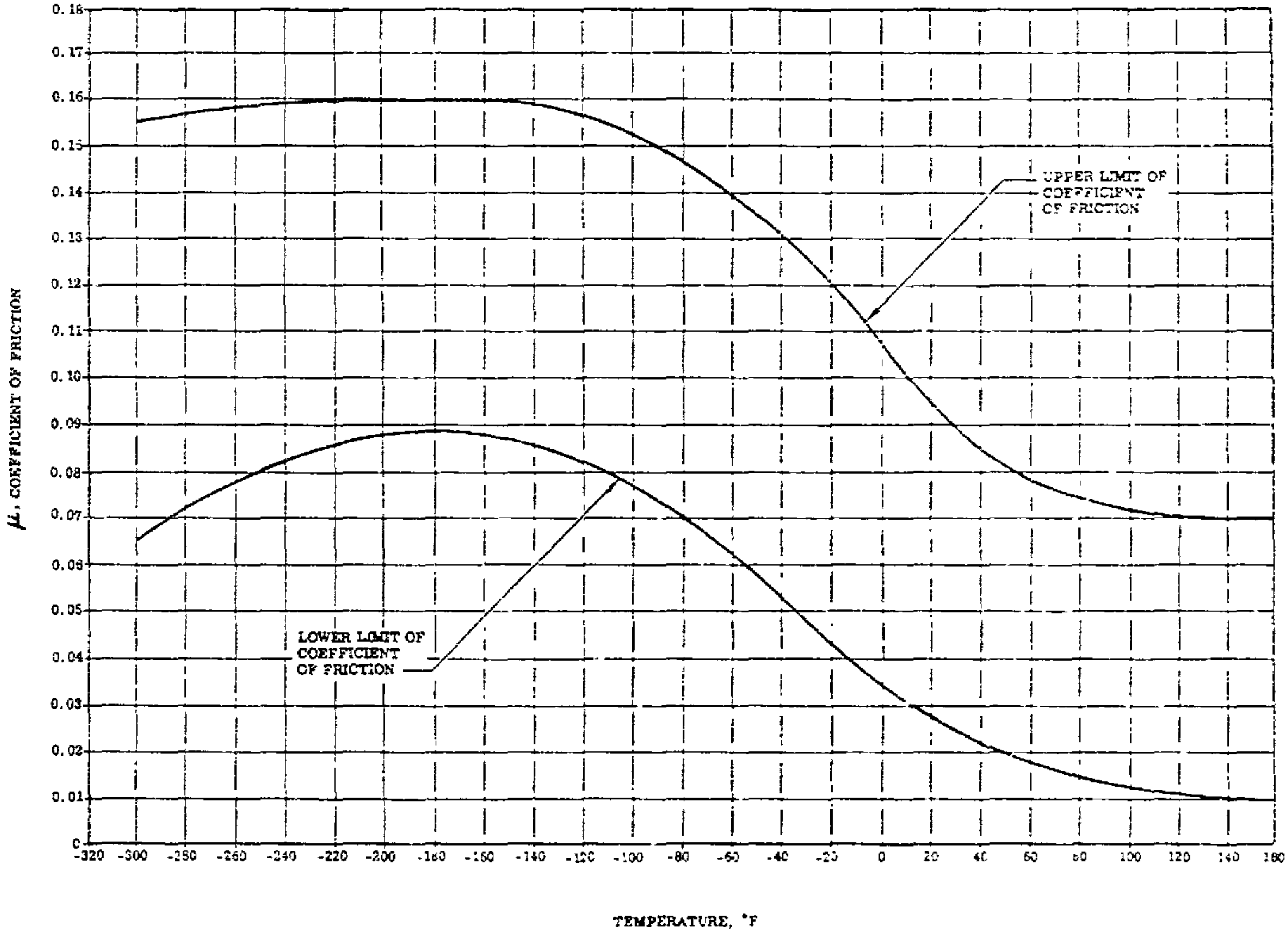
NOTE

Figure 9-19 shows the generate configuration of the spherical-type gimbal bearing.



J2-1-53

Figure 9-16. Static Coefficient of Friction of Gimbal Spherical-Surface, Fabroid Bearing Material. Based on 2.70-Inch Spherical Radius



J2-1-54

Figure 9-17. Dynamic Coefficient of Friction of Gimbal Spherical-Surface, Fabroid Bearing Material, Based on 2.70-Inch Spherical Radius

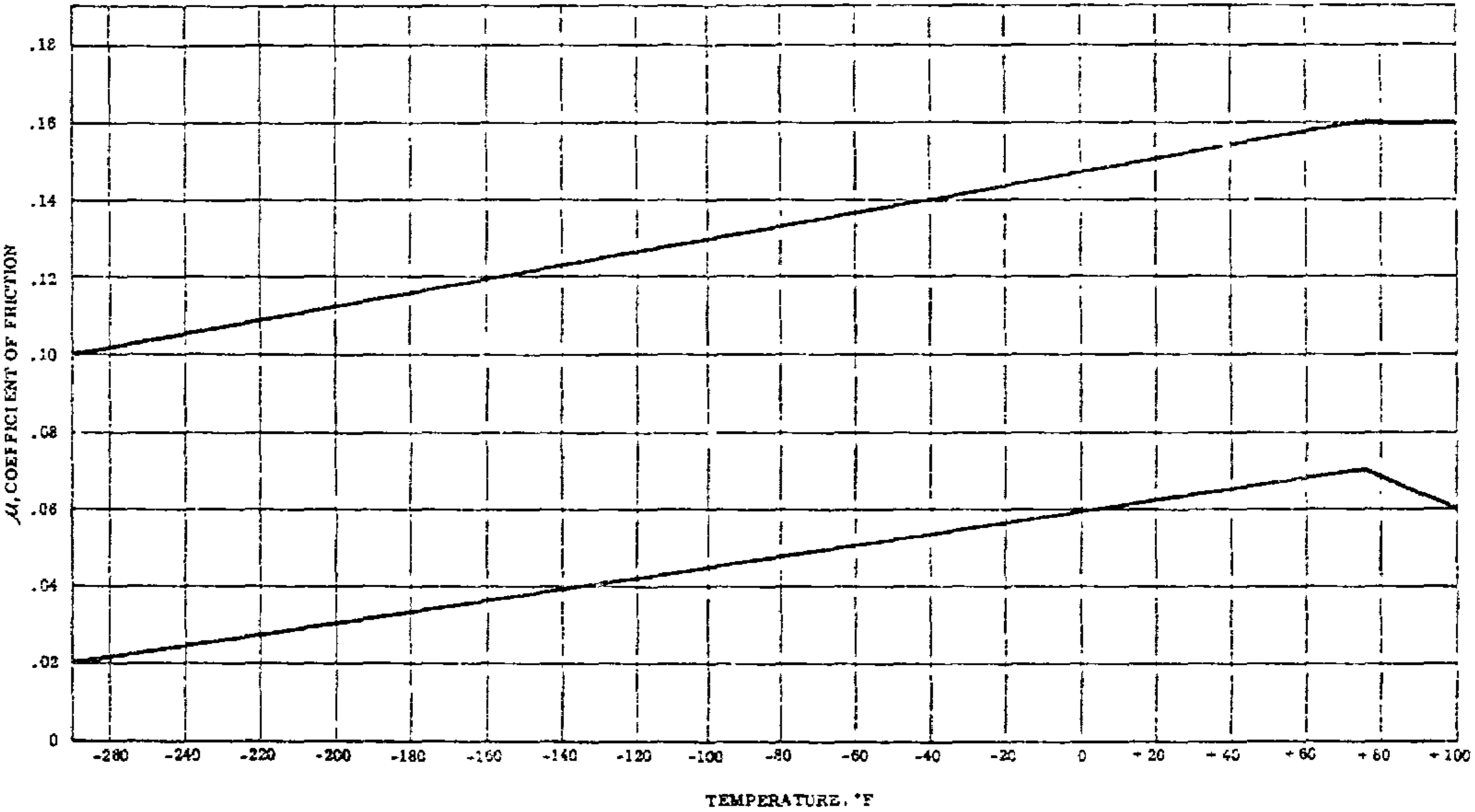
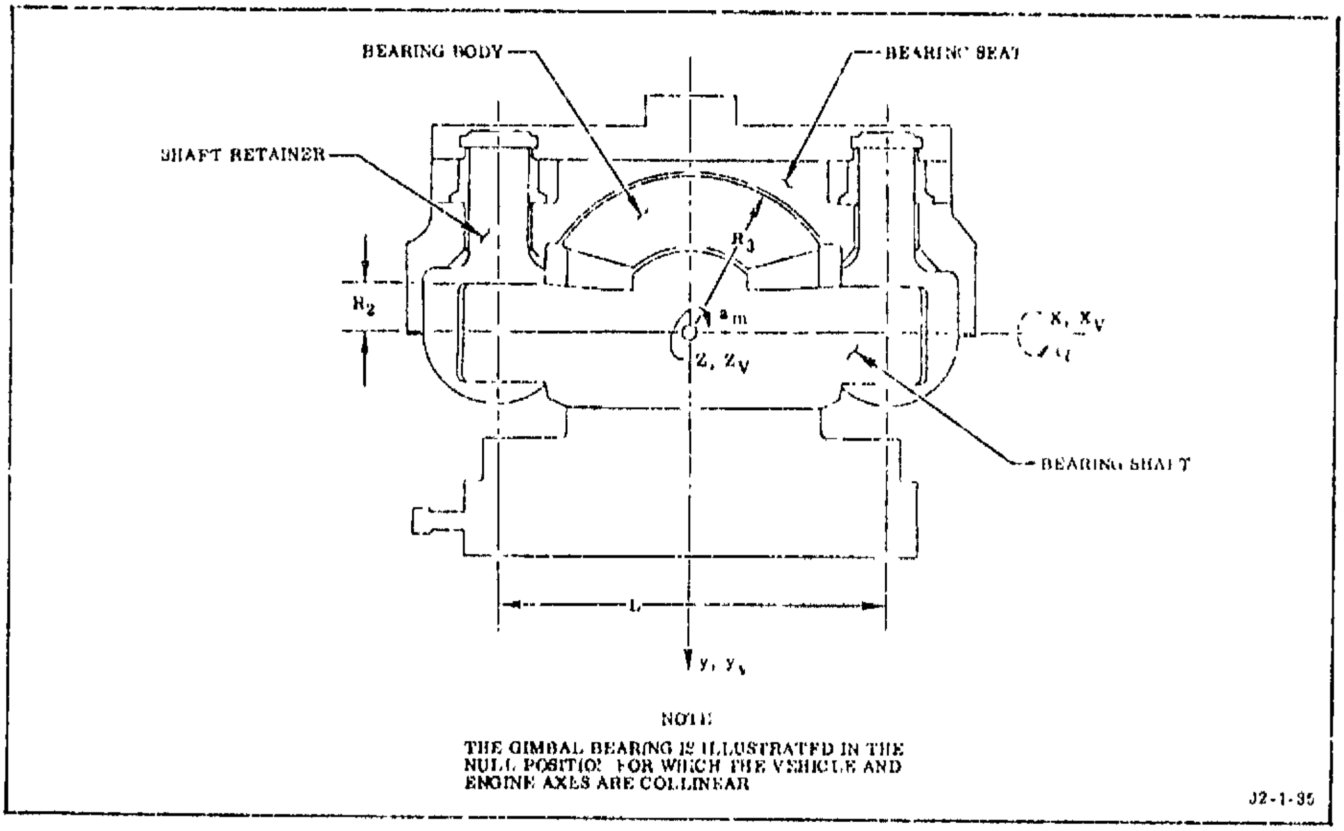


Figure 9-18. Coefficient of Friction Band of Dry-Film Lubricant RA0112-006 (Rocketdyne) (Static and Dynamic)



NOTE:
THE GIMBAL BEARING IS ILLUSTRATED IN THE NULL POSITION FOR WHICH THE VEHICLE AND ENGINE AXES ARE COLLINEAR

Figure 9-19. Engine Gimbal Configuration

9-34. The definitions of the gimbal-bearing parameters for equations of paragraph 9-33 are given below:

M_{x_v}, M_{y_v}, M_{z_v}	(in-lb)	- The resultant applied moments at the gimbal center in a coordinate system which is fixed to the vehicle and is parallel to the engine coordinate system when the engine has a zero degree gimbal angle.
F_x, F_y, F_z M_x, M_y, M_z	(lb) (in-lb)	- The resultant applied forces and moments at the gimbal center in the engine coordinate system.
α_f, α_m	(deg)	- The engine gimbal angles. α_f is a positive rotation about the axis fixed from canting on the vehicle side of the gimbal; $\alpha_f = \alpha_{x_v}$ α_m is a positive rotation about the axis that cants (moves) with respect to the vehicle side of the gimbal; $\alpha_m = \alpha_z$
R_2	(in.)	- The radius of shaft at the retainers.

R_3 (in.) - The radius of the body and seat.

L (in.) - The length of shaft between centers of retainers.

μ_1 $(\frac{lb}{lb})$ - The coefficient of friction between the flat portion of the gimbal bearing shaft and the body (a positive quantity).

μ_2 $(\frac{lb}{lb})$ - The coefficient of friction between the retainer and the shaft (a positive quantity).

μ_3 $(\frac{lb}{lb})$ - The coefficient of friction between the body and the seat (a positive quantity).

ϵ (deg) - The angle in the $x_v - z_v$ plane defining the axis, A_ϵ (figure 9-20), about which the engine is gimbaling or about which rotation is imminent. Positive rotation about the axis, A_ϵ, is determined by the right-hand rule.

NOTE

$k_1 = \pm 1$, $k_2 = \pm 1$, the choice of +1 or -1 for k is made so that the second term has the same sign as the first term on the right-hand side of the respective equation. The following exceptions, however, must be observed:

1) for $\epsilon = n\pi$; $k_1 = 0$

2) for $\epsilon = (2n + 1)\frac{\pi}{2}$, $k_2 = 0$

where n = 0, 1, 2, 3, ...

9-35. NONGIMBALED ENGINE LOADS. The information presented in figure 9-21 is applicable to nongimbaled engines where the vehicle propellant ducts are connected directly to the turbopump inlet flanges.

9-36. GIMBALING LIMITATIONS. The gimbaling limitation of the customer connect lines and propellant inlet ducts and the gimbaling limitation of the gimbal bearing are shown in figure 9-22. The allowable gimbaling includes cycles accumulated under all conditions of engine usage, such as engine operating or non-operating, pressurized or nonpressurized, and chilled or nonchilled. A cycle is defined as either (1) gimbaling from null position to a particular angle, then returning through null to the opposite angle and back to null or (2) gimbaling from null position to a corner angle, then around a square gimbal pattern through the other three corner angles, then back to the original corner angle, and (optional) back to null. Any gimbal movement that is less than the defined cycle must be recorded in the Engine Log Book as a half cycle. Figure 9-22 shows the percentage of design life expended for each cycle at a particular angular excursion. The percentage per cycle must be multiplied by the number of cycles at that particular angular excursion to determine the cumulative percent of design life expended. For square-pattern gimbaling, the number of square-pattern cycles must be multiplied first by 1.5 to obtain a corrected number of cycles. To make sure that gimbaling limitations are not exceeded, the cumulative total of percentages of design life expended must not exceed 100 percent. An example of calculations to determine design life expended for gimbal bearing (under typical conditions) follows:

(1) Series of gimbal cycles executed:
Two cycles at 0.6 degrees
Eight square-pattern cycles at 6.0 degrees
Four cycles at 9.4 degrees

(2) Percent of design life expended per cycle (figure 9-22):
At 0.6 degrees, 0.0117 percent
At 6.0 degrees, 0.102 percent
At 9.4 degrees, 0.28 percent

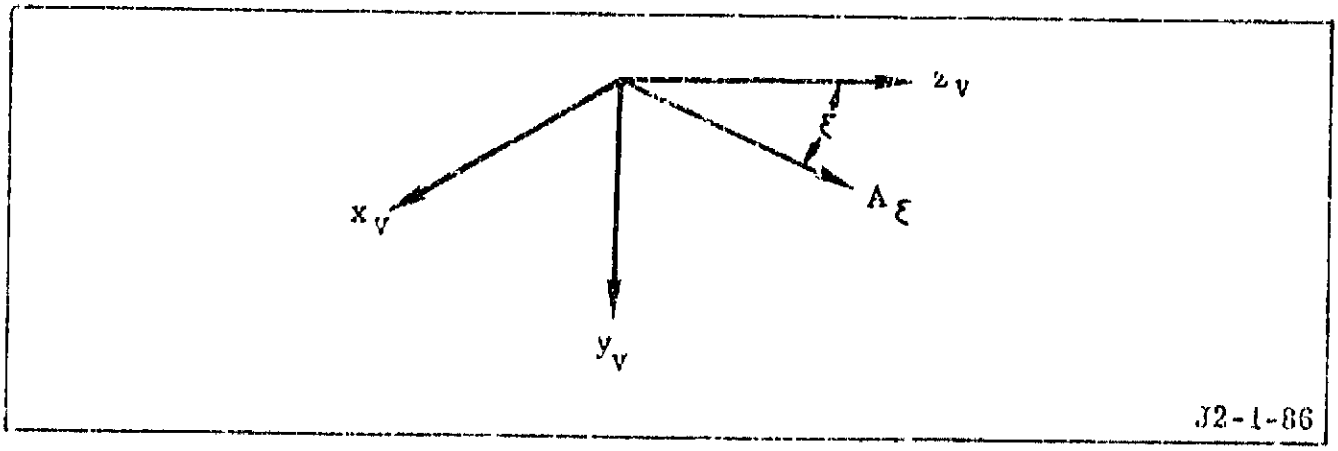


Figure 9-20. Axis Definition

(3) Percent of design life expended for total cycles at each particular angular excursion (ie, percentages to be entered in Engine Log Book):

At 0.6 degrees: 2 x 0.0117 = 0.0234 percent
At 6.0 degrees (square pattern): corrected number of cycles = 1.5 x 8 = 12, and 12 x 0.102 = 1.224 percent
At 9.4 degrees: 4 x 0.28 = 1.12 percent

NOTE

Total cumulative percentages of design life expended for this series of gimbal cycles is 2.3674 percent, but this total percentage value is not entered in the Engine Log Book.

9-37. THRUST ALINEMENT.

9-38. The actual thrust vector must be within 43 minutes of the engine centerline and must pass within 0.550 inch, or 0.693 inch on engines incorporating MD200 change, of the gimbal center.

CAUTION

The vehicle contractor must not adjust the engine gimbal bearing to obtain alinement with the vehicle attach point.

9-39. ELECTRICAL AND FLUID CUSTOMER CONNECTION LOADS.

9-40. Applied loads at the vehicle connections caused by gimbaling the engine are listed in figure 9-24. Loads due to acceleration and vibration are listed in figure 9-25.

9-41. HEAT SHIELD ATTACHMENT.

9-42. The heat shield attachment is shown on the applicable engine installation drawing. The maximum load which may be applied is 12 lb/in in any direction.

9-43. ACTUATOR ATTACH POINTS.

9-44. In addition to basic support from the gimbal block, the engine is supported by two gimbal actuators attached to the thrust chamber injector dome, each 90 degrees from the other with respect to the centerline of thrust. The actuator envelope and installation requirements are described in figure 9-26 and on the applicable engine installation drawing. The two actuators and the installation bolts or pins are not supplied with the engine. The data in figure 9-23 presents a summary of engine spring rates. They are based on a combination of test data and analytical calculations. Figure 9-23 also outlines expected variations in spring rates from engine to engine.

1. Installation Misalinements of the Turbopump Interfaces From Their Nominal Position

(Refer to Customer Connect Interface Drawing 106175.)

2. Load Deflections of the Turbopump Interfaces From Their Installed Positions

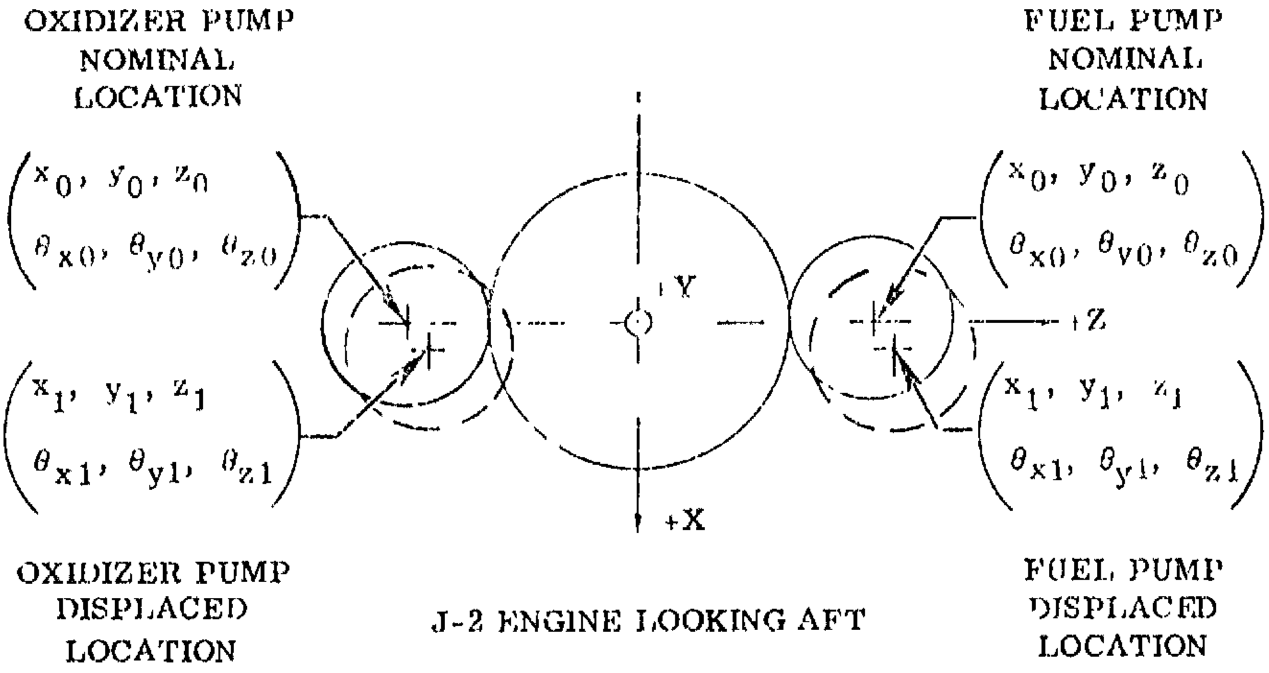
	Δ_x Oxidizer (in.)	Δ_x Fuel (in.)	Δ_z (in.)	Δ_y (in.)	θ_{xz} (deg)	θ_{yL} Oxidizer (deg)	θ_{yF} Fuel (deg)
Maximum Range of Motion	0.760	0.910	0.10	0.10	0.50	2.20	3.50
Maximum Motion in Either the Plus or Minus Direction From the Installed Position	0.450	0.545	0.05	0.05	0.50	1.30	1.95

3. Approximate Kinematic Movements for the Turbopump Interfaces Relative to Their Deflected Positions Caused by Engine Gimbaling (Determined From 1 and 2)

	Δ_x (in.)	Δ_y (in.)	Δ_z (in.)	θ_x (rad)	θ_y (rad)	θ_z (rad)
Oxidizer	$(-11.\alpha_z - 21.T)$	$21.\alpha_x$	$11.\alpha_x$	α_x	T	α_z
Fuel	$(-6.\alpha_z + 21.T)$	$-21.\alpha_x$	$6.\alpha_x$	α_x	T	α_z

where $T = \mathrm{Cot}^{-1}\left(\frac{\sin\alpha_x}{\tan\alpha_z}\right) - \mathrm{Tan}^{-1}\left(\frac{\sin\alpha_z}{\tan\alpha_x}\right)$

Figure 9-21. Nongimbaled Engine Loads (Sheet 1 of 3)



J-2 ENGINE LOOKING AFT

$$\Delta_x = x_1 - x_0 \qquad \theta_x = \theta_{x1} - \theta_{x0}$$

$$\Delta_y = y_1 - y_0 \qquad \theta_y = \theta_{y1} - \theta_{y0}$$

$$\Delta_z = z_1 - z_0 \qquad \theta_z = \theta_{z1} - \theta_{z0}$$

$$\Delta_{xz} = \sqrt{(x_1 - x_0)^2 + (z_1 - z_0)^2}$$

$$\theta_{xz} = \sqrt{(\theta_{x1} - \theta_{x0})^2 + (\theta_{z1} - \theta_{z0})^2}$$

1 THE Δ_x AND THE Δ_{xz} MISALINEMENTS FOR EACH CASE ARE VECTORILY ADDITIVE.

2 THE α_x AND THE α_z ARE ANGLES (IN RADIANS) OF ROTATION ABOUT THE J-2 ENGINE X AND Z AXES.

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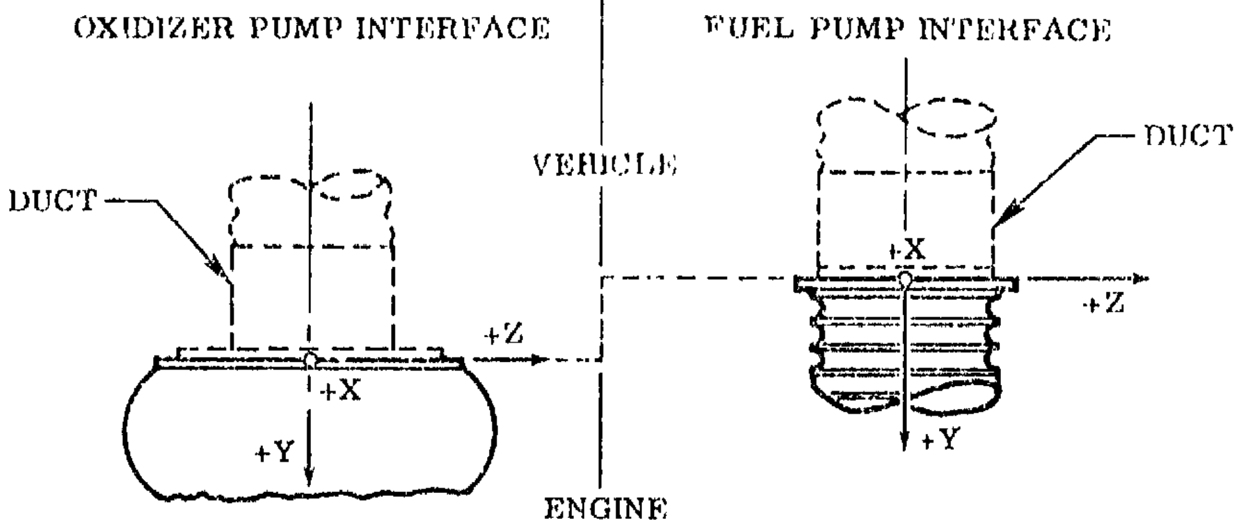
Figure 9-21. Nongimbaled Engine Loads (Sheet 2 of 3)

ALLOWABLE LOADS AT THE PUMP INTERFACES FROM THE VEHICLE INLET DUCTS



LOADS CARRIED BY DUCT INTO TURBOPUMPS ①

Oxidizer pump interface	Fuel pump interface
F_{xz} = 1,500 LB	F_{xz} = 1,850 LB
F_y = ±1,960 LB	F_y = ±2,160 LB
M_{xz} = 5,000 IN. -LB	M_{xz} = 8,750 IN. -LB
M_y = 24,000 IN. -LB -25,000 IN. -LB	M_y = 24,000 IN. -LB -32,000 IN. -LB

THESE LOADS INCLUDE ANY SPRING-RATE LOADS, INERTIAL LOADS AND LATERAL LOADS FROM PRESSURIZING THE DUCTS

PRESSURE LOAD ON THE PUMP ACROSS THE INTERFACE PLANE DURING ENGINE OPERATION

Oxidizer	Fuel
F_y MAX. = 8,920 LB	F_y MAX. = 8,440 LB
F_y MIN. 1,260 LB	F_y MIN. 1,260 LB

① THESE LOADS MUST BE UNIFORMLY DISTRIBUTED INTO THE PUMP

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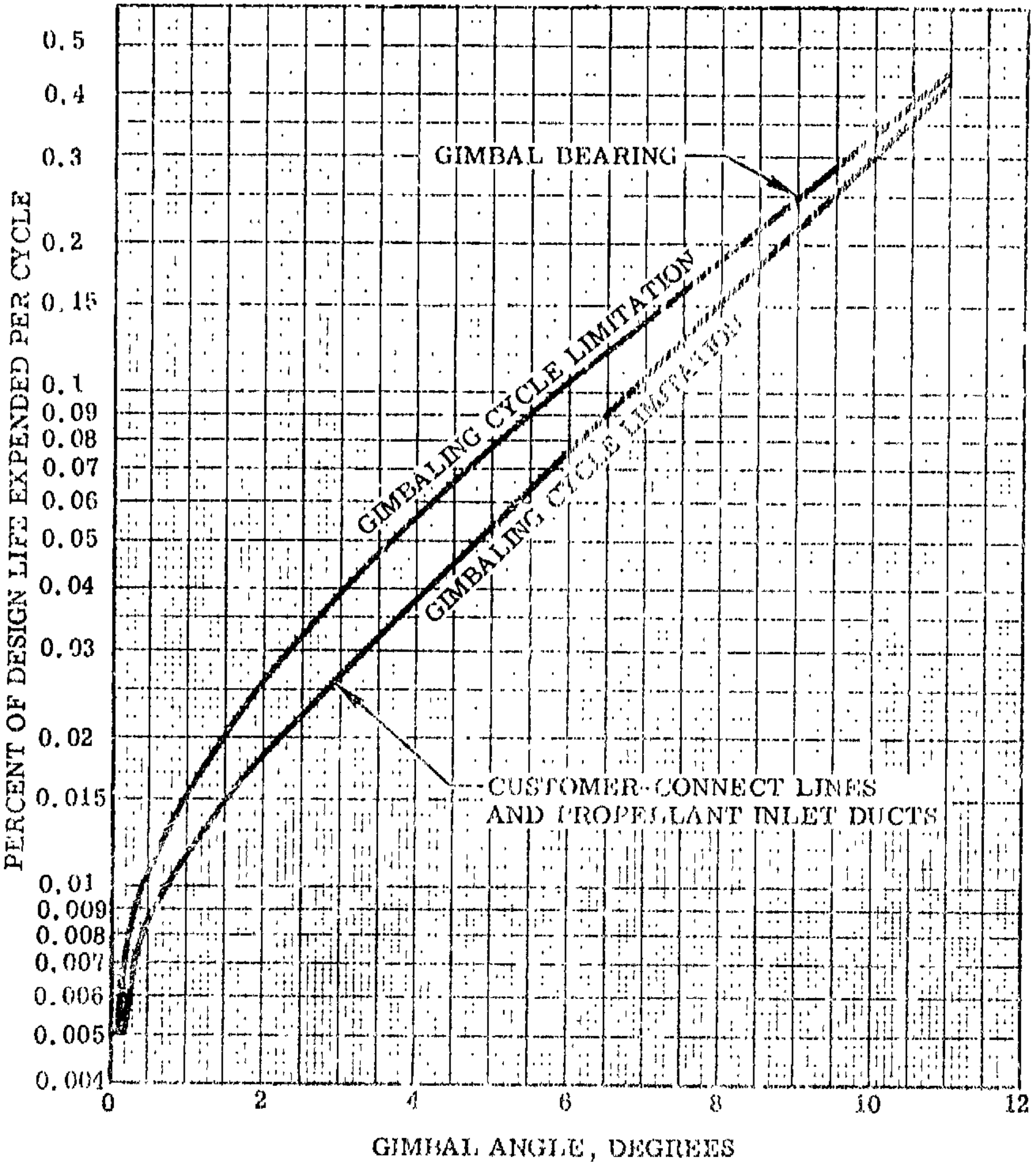
Figure 9-21. Nongimbaled Engine Loads (Sheet 3 of 3)



J2-11-38A

Figure 9-22. Gimbaling Limitations

Spring Rate Description	Symbol	Average Spring Rate Value x10^{-6}	Expected Variation in Spring Rates x10^{-6}	Per-cent	Units
Actuator attach point 1 to dome-chamber interface (Y direction)	k_1	5.	2.5 to 7.5	±50	lb/in
Actuator attach point 2 to dome-chamber interface (Y direction)	k_2	5.	2.5 to 7.5	±50	lb/in
Gimbal center to dome(a) (entire flexibility of gimbal lumped to engine side of gimbal) ten. comp.	k_{3T} k_{3C}	1.3 11.	1.0 to 1.6 8.25 to 13.7	±25 ±25	lb/in lb/in
Dome to chamber (axial independent of chamber pressure)	k_4	3.25	2.45 to 4.10	±25	lb/in
Dome to chamber (axial dependent only on chamber pressure)	k_5	0.0193	0.0145 to 0.0240	±25	psi/in
Dome to chamber - bending about X axis	k_{6X}	63.	31.5 to 94.5	±50	in-lb/rad.
about Z axis	k_{6Z}	63.	31.5 to 94.5	±50	in-lb/rad.
Gimbal to dome - bending about X axis	k_{7X}	132.	53. to 212.	±60	in-lb/rad.
about Z axis	k_{7Z}	132.	53. to 212.	±60	in-lb/rad.
Gimbal to chamber-torsion(b)	k_8	13.8	10.3 to 17.3	±25	in-lb/rad.
Actuator attach point to vehicle interface (assumes the load applied at the attach point is entirely reacted at the vehicle interface)	k_e	0.255	.128 to .515	+100 -50	lb/in
Actuator attach point to vehicle interface (assumes frictionless pivot at gimbal center and inertial reaction at the center of percussion)	k_f	1.61	1.20 to 2.45	+50 -25	lb/in

(a) The axial dead zone (clearance) in the gimbal bearing is 0.018 ±0.013 inch.

(b) The total twist dead zone (clearance) in the engine is less than 0.39 degree.

Figure 9-23. Engine Spring Rates (Sheet 1 of 2)

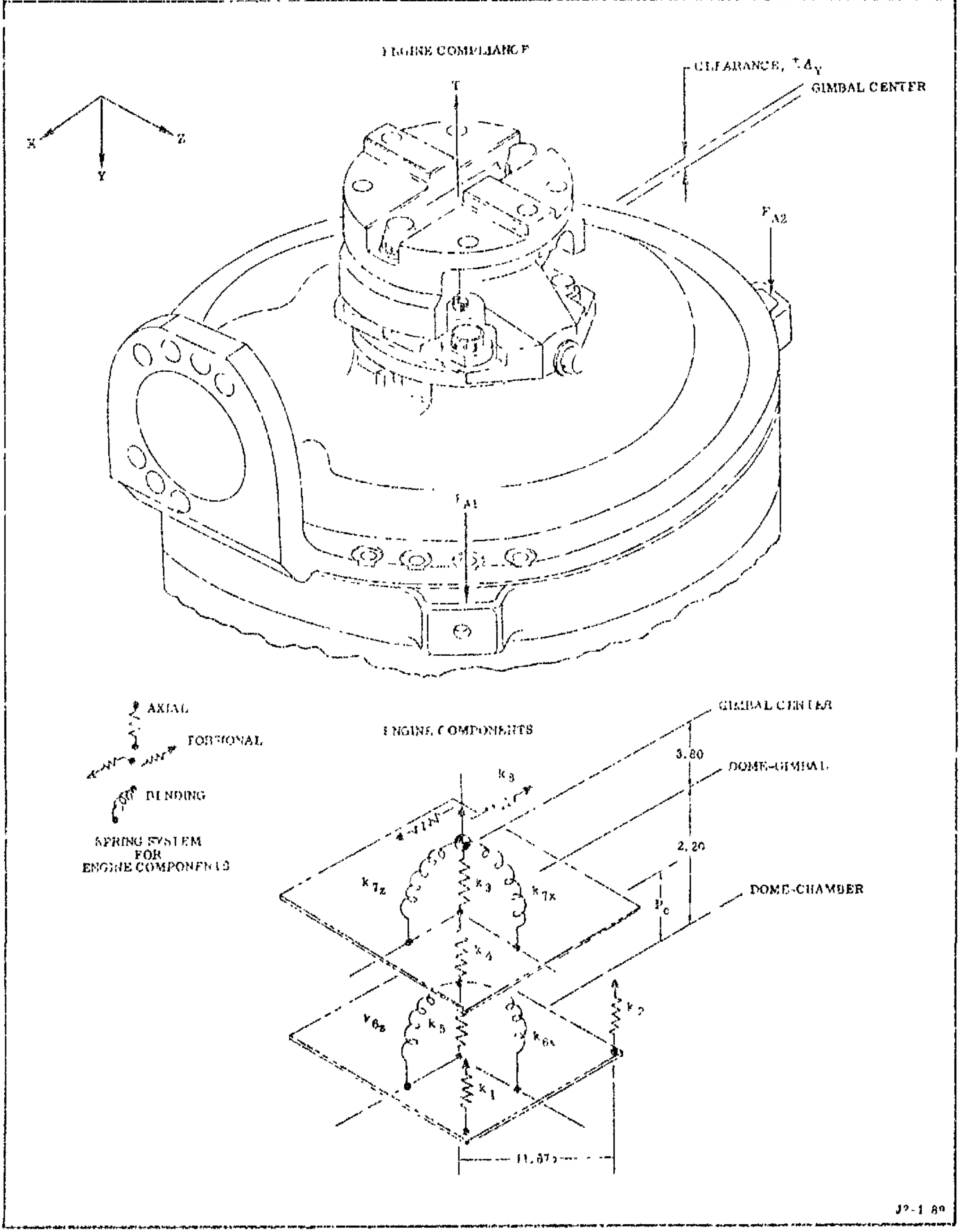


Figure 9-23. Engine Spring Rates (Sheet 2 of 2)

Loads, Caused by Deflection of Fluid Lines Due to Gimbaling, Applied at Vehicle Connection

Gimbal Position	F_x lb	F_y lb	F_z lb	M_x in-lb	M_y in-lb	M_z in-lb
2	+607	+902	+166	-11880	-5218	+6989
3	+277	+247	+160	- 3331	-2352	+1488
4	-331	-836	-144	+ 9058	+3072	-1051
5	-473	-870	-160	+10555	+4205	-1728
6	-607	-902	-166	+11880	+5218	-2189
7	-277	-247	-160	+ 3331	+2352	-1488
8	+331	+836	+144	- 9058	-3072	+1051
9	+473	+870	+160	-10555	-4205	+1728

Loads, Caused by Deflection of Electric Lines Due to Gimbaling, Applied at Vehicle Connection

Gimbal Position	F_x lb	F_y lb	F_z lb	M_x in-lb	M_y in-lb	M_z in-lb
2	-321	-410	+274	+4581	+443	+5538
3	-289	-361	+221	+3734	+ 49	+4893
4	-255	-306	+168	+2886	-341	+4248
5	+ 25	+ 44	- 50	- 806	-447	+ 515
6	+321	+410	-274	-4581	-443	-5538
7	+289	+361	-221	-3734	- 49	-4893
8	+255	+306	-168	-2886	+341	-4248
9	- 25	- 44	+ 50	+ 806	+447	- 515

Figure 9-24. Bending Loads From Customer Connect Lines Caused by Gimbaling the Engine

9-45. GIMBAL ACTUATOR LOADS.

9-46. The loads imposed by the gimbal actuators must not exceed 46,000 pounds applied to each actuator chamber attach point when the engine is being gimbaled. If the engine is locked in the neutral position, ±1.6 degrees, it is capable of withstanding actuator loads of 130,000 pounds maximum.

9-47. OPERATIONAL AND GIMBALING LOADS.

9-48. MOVEMENT. The engine is designed to withstand a 7.5-degree maximum gimbal angle in the plane of either actuator. The resultant corner position for simultaneous actuator extension or retraction is approximately 10 degrees 30 minutes. Overtravel positive stop provisions must be an integral part of the actuator.

DEFINITIONS

G_x = Acceleration in the x direction, in g's, due to vibration and vehicle acceleration.

G_y = Acceleration in the y direction, in g's, due to vibration and vehicle acceleration.

G_z = Acceleration in the z direction, in g's, due to vibration and vehicle acceleration.

$\dot{\alpha}_x$ = Angular acceleration about the x axis, in rad/sec^2, due to engine gimbaling.

$\dot{\alpha}_z$ = Angular acceleration about the z axis, in rad/sec^2, due to engine gimbaling.

The above terms used in the following equations will give:

$F_{(x,\ y,\ \text{or}\ z)}$, in pounds

$M_{(x,\ y,\ \text{or}\ z)}$, in inch-pounds

LOADS AT VEHICLE CONNECTION

Loads due to Fluid Lines:

$F_x = -40.7\ G_x - 1.5\dot{\alpha}_z$

$F_y = -40.7\ G_y - 1.9\dot{\alpha}_z - 2.3\dot{\alpha}_x$

$F_z = -40.7\ G_z - 1.7\dot{\alpha}_x$

$M_x = +342\ G_y + 1188\ G_z - 118\dot{\alpha}_x - 19.2\dot{\alpha}_z$

$M_y = -342\ G_x - 476\ G_z + 15.2\dot{\alpha}_z + 13.1\dot{\alpha}_x$

$M_z = -1188\ G_x + 476\ G_y - 18\dot{\alpha}_x + 69\dot{\alpha}_z$

Loads Due to Electrical Lines:

$F_x = -73\ G_x - 4.2\dot{\alpha}_z$

$F_y = -73\ G_y - 5.5\dot{\alpha}_z - 7.3\dot{\alpha}_x$

$F_z = -73\ G_z + 5.2\dot{\alpha}_x$

$M_x = -190\ G_y + 2102\ G_z + 401\dot{\alpha}_x + 12\dot{\alpha}_z$

$M_y = +190\ G_x + 329\ G_z - 9.2\dot{\alpha}_z + 58.2\dot{\alpha}_x$

$M_z = -2102\ G_x - 329\ G_y + 82\dot{\alpha}_x + 373\dot{\alpha}_z$

Figure 9-25. Customer Connect Line Loads Due to Acceleration and Vibration of Customer Connect Lines

9-49. ACCELERATION AND VELOCITY. Engine gimbal angular acceleration must not exceed 80 rad/sec^2. During the boost phase of flight, before engine ignition, the engine must not be subjected to accelerations greater than presented in figure 9-27.

9-50. FLIGHT LOAD LIMITS. During the engine operation phase of flight, the following load conditions should not be exceeded:

a. The longitudinal and lateral inertia load limits as shown in figures 9-28 and 9-29.

b. Aerodynamic moments during gimbal operation must not exceed the following and must be such that, when combined with all other loads, other maximum limitation specifications in this manual are not exceeded:

(1) No. 1 or No. 2 gimbal axis (figure 9-6): aerodynamic moments of ±110,000 inch-pounds.

(2) X or Z engine axis (figure 9-6): aerodynamic moments of ±210,000 inch-pounds.

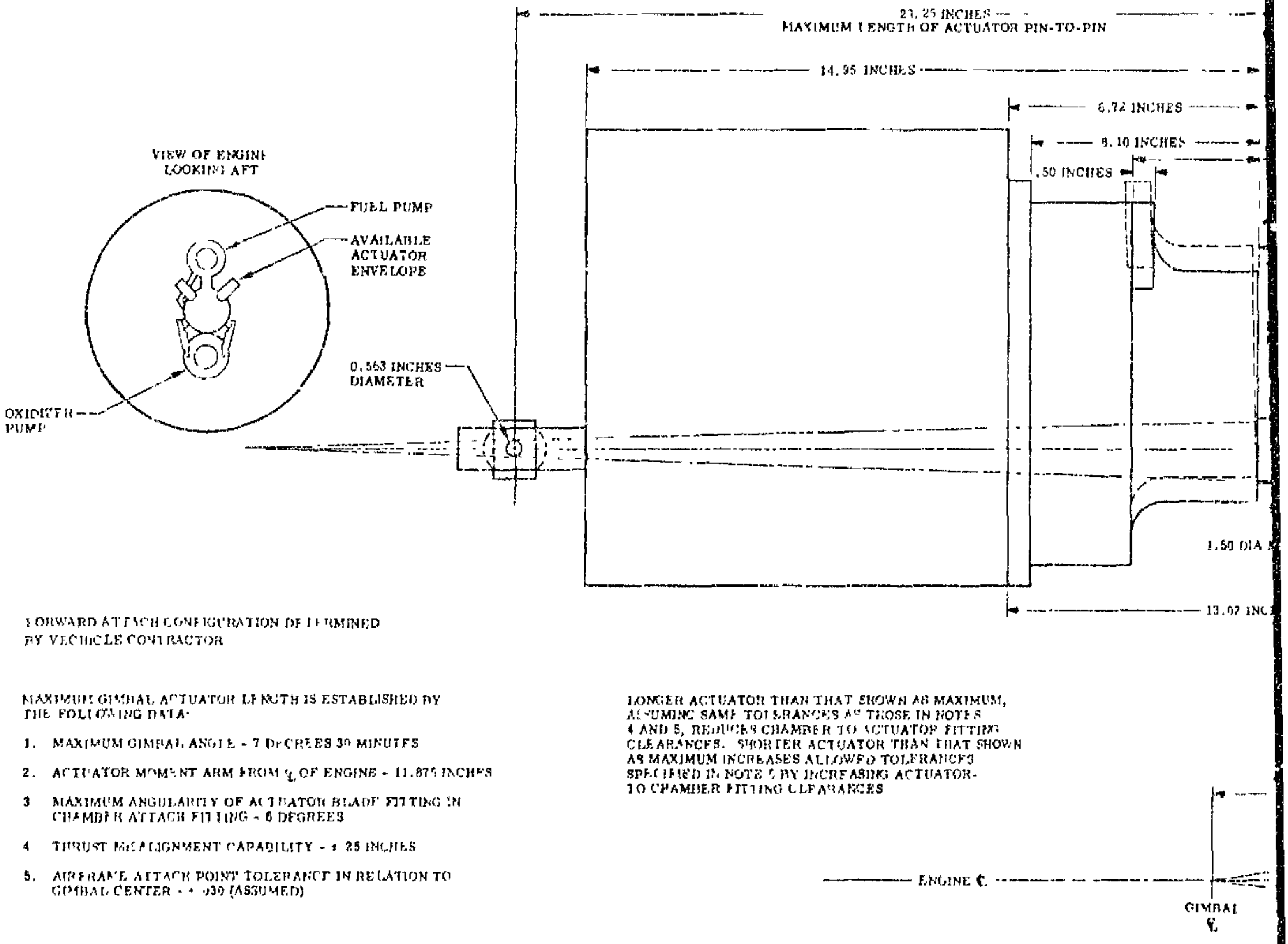
c. Maximum aerodynamic pressure on thrust chamber must not exceed 500 lb/sq ft.

9-51. GIMBALING AND VEHICLE LOADS. The designed limit of forward acceleration with respect to engine gimbal angle is shown in figure 9-29. This limit occurs simultaneously with the lateral acceleration relationship to forward acceleration as shown in figure 9-28.

9-52. INLET DUCT LOADS AT GIMBAL CENTER.

9-53. The following equations specify the inlet duct loads at the gimbal center as a function of the gimbal angles of the engine, duct spring rates, and duct pressures. The effects of installation misalinements and frictional loads have been included so that they can be used in calculating the maximum load conditions at any gimbal angle. Figure 9-30 defines the terminology used in these equations.

Pages 9-34A and 9-34B deleted.



FORWARD ATTACH CONFIGURATION DETERMINED BY VEHICLE CONTRACTOR

MAXIMUM GIMBAL ACTUATOR LENGTH IS ESTABLISHED BY THE FOLLOWING DATA:

1. MAXIMUM GIMBAL ANGLE - 7 DEGREES 30 MINUTES
2. ACTUATOR MOMENT ARM FROM ℄ OF ENGINE - 11.875 INCHES
3. MAXIMUM ANGULARITY OF ACTUATOR BLADE FITTING IN CHAMBER ATTACH FITTING - 6 DEGREES
4. THRUST MISALIGNMENT CAPABILITY - ± .25 INCHES
5. AIRFRAME ATTACH POINT TOLERANCE IN RELATION TO GIMBAL CENTER - ± .030 (ASSUMED)

LONGER ACTUATOR THAN THAT SHOWN AS MAXIMUM, ASSUMING SAME TOLERANCES AS THOSE IN NOTES 4 AND 5, REDUCES CHAMBER TO ACTUATOR FITTING CLEARANCES. SHORTER ACTUATOR THAN THAT SHOWN AS MAXIMUM INCREASES ALLOWED TOLERANCES SPECIFIED IN NOTE 5 BY INCREASING ACTUATOR-TO CHAMBER FITTING CLEARANCES

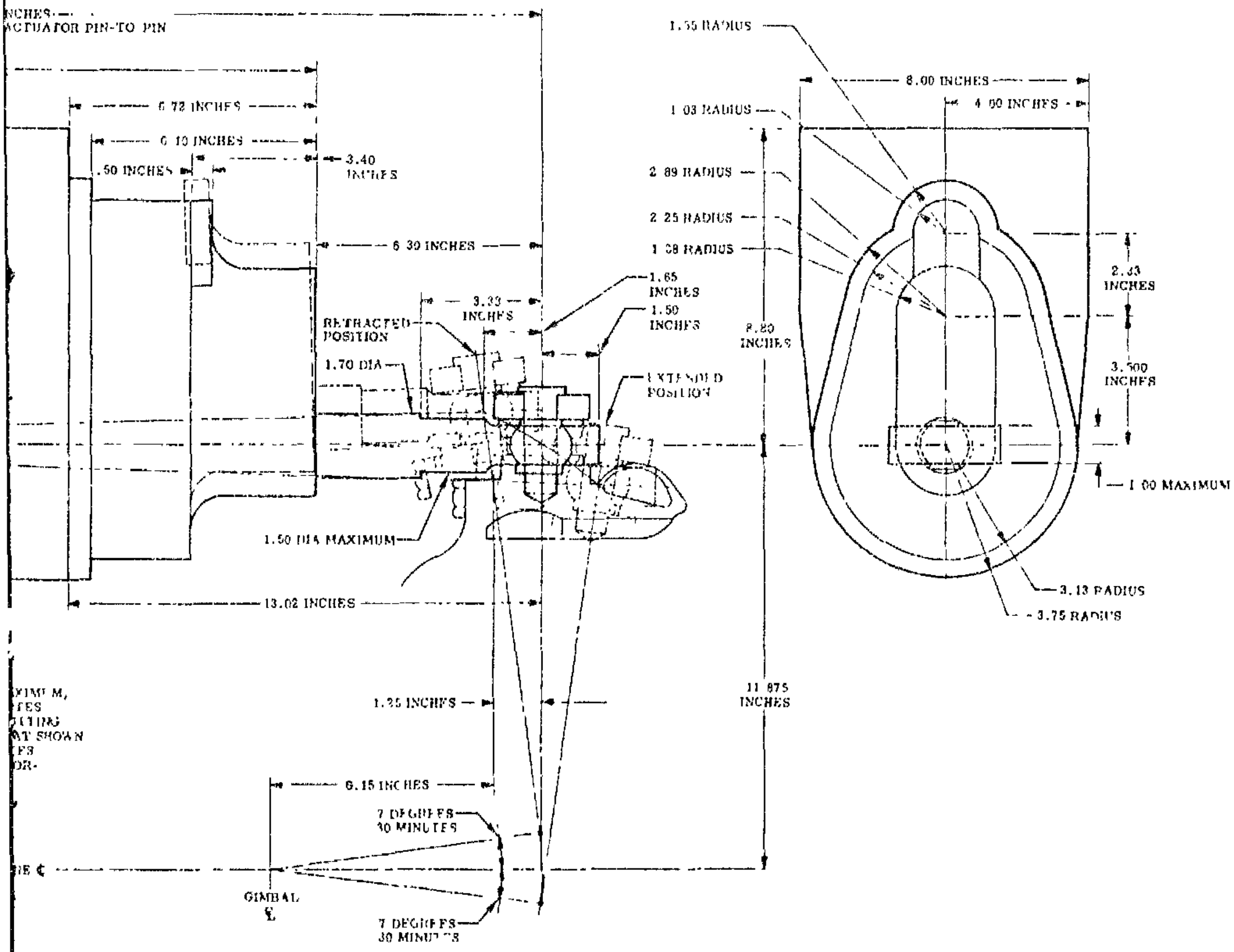


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Figure 9-26. Gimbal Actuator Envelope

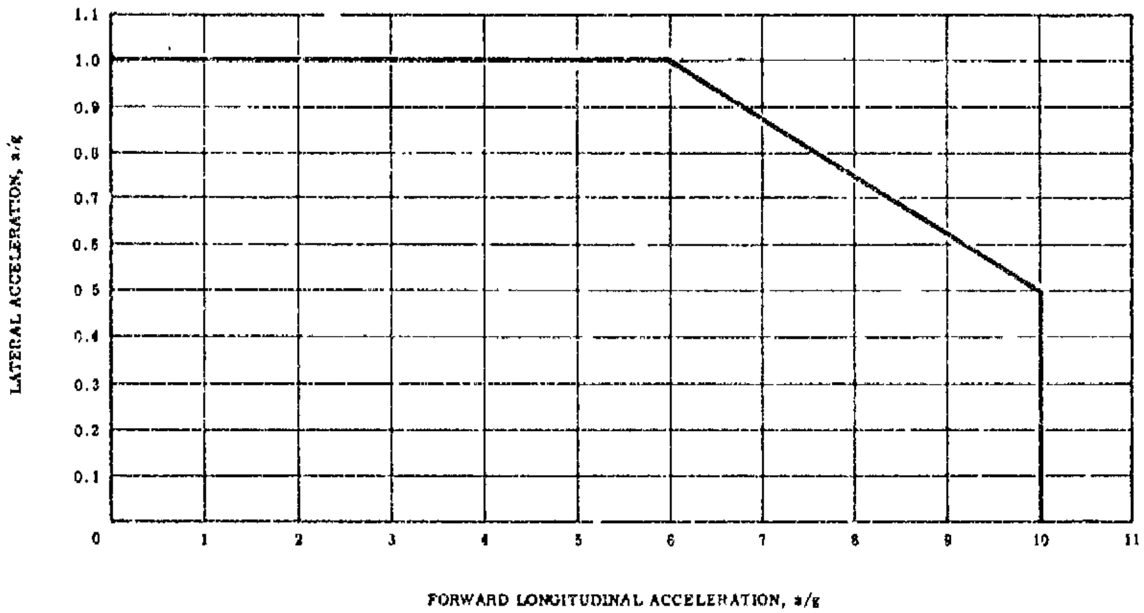

Figure 9-27. Boost-Phase Load Factors at Zero Thrust

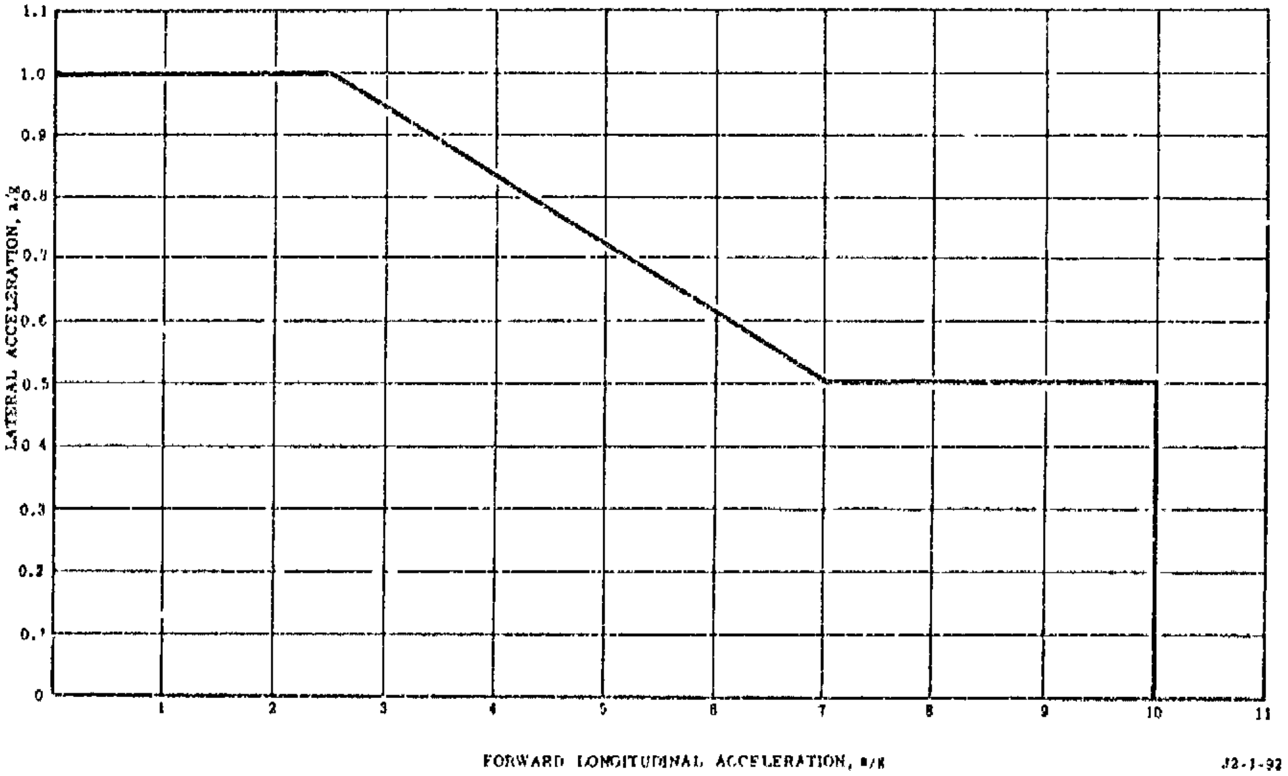

Figure 9-28. Flight Load Factors Resulting From Engine Thrust

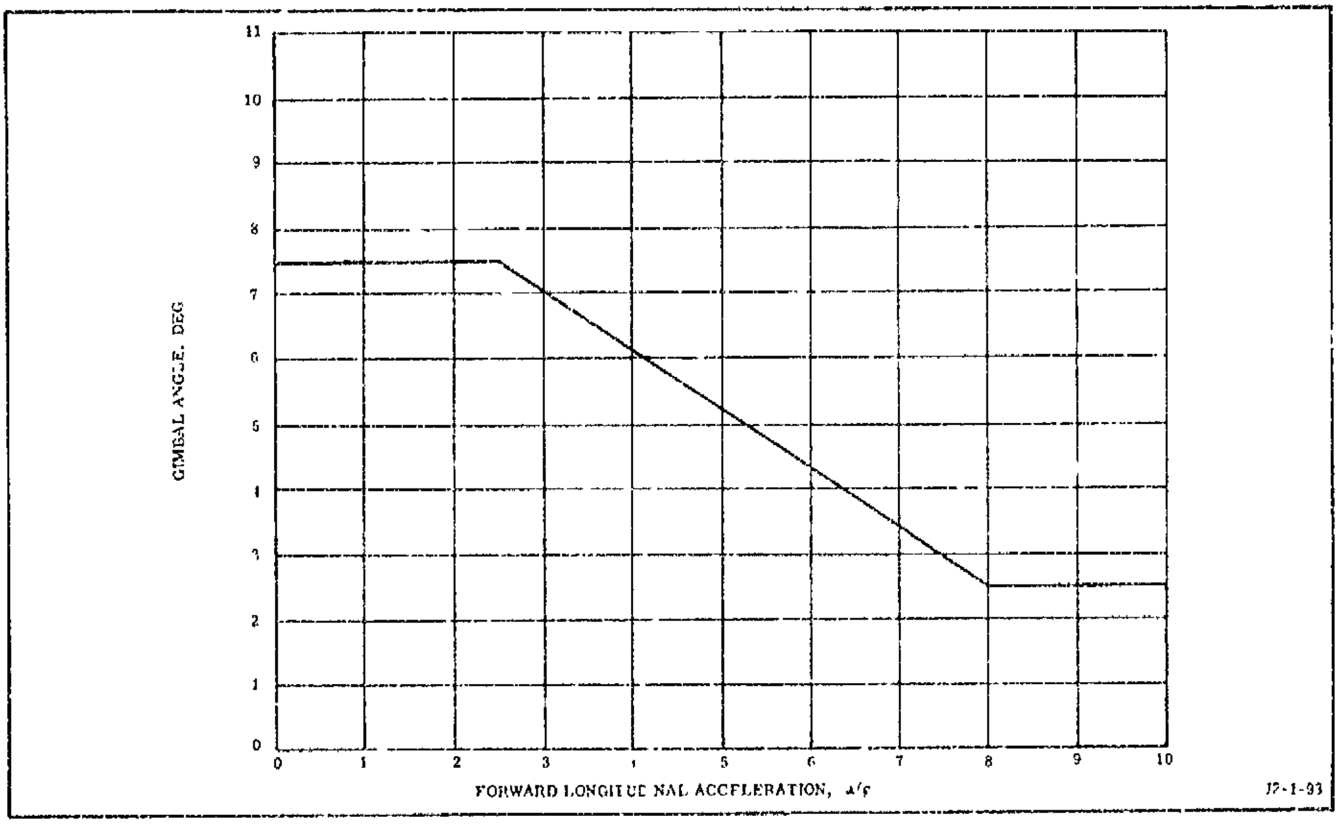

Figure 9-29. Limit of Forward Acceleration Versus Engine Gimbal Angle

a. Equations for applied loads at the pumps due to the inlet ducts:

(1) Oxidizer duct.

$$(P_{y_d})_L = (62.\ p_L + .6K_L + 250.) - .366\,\alpha_f\,K_L \tag{1.1}$$

$$(P_{z_d})_L = -\frac{\gamma}{114.6}\,(P_{y_d})_L \tag{1.2}$$

$$(M_{x_d})_L = -(P_{z_d})_L\,(3.18 - .0688\alpha_f) - K_{\theta L}\,\frac{\gamma}{2} \tag{1.3}$$

(2) Fuel duct.

$$L_2 = 3.5 - .128\alpha_f \qquad (2.1)$$

$$L_1 = 11.5 - .183\alpha_f \qquad (2.2)$$

$$(P_{y_d})_F = (62.\,p_F \pm .6K_F \pm 250.) + .366\alpha_f \; K_F \qquad (2.3)$$

$$(P_{z_d})_F = -\frac{\gamma}{57.3}(P_{y_d})_F \left(1 - \frac{L_2}{4L_1}\right) + K_{\theta F}\frac{\gamma}{L_1} \qquad (2.4)$$

$$(M_{x_d})_F = \frac{\gamma L_2}{57.3}(P_{y_d})_F \left(.75 - \frac{L_2}{4L_1}\right) - K_{\theta F}\,\gamma\left(1 + \frac{L_2}{L_1}\right) \qquad (2.5)$$

NOTE

The plus and minus (±) quantities in equations (1.1) and (2.3) furnish a load range that accounts for the loads from installation deflections (±.6K) and friction loads from the bipod joints (±250.) during deflection of the duct.

b. Equations for resultant loads at the gimbal center:

$$(P_x)_G = (L.\ L.\ F.)\left[(P_{z_d})_L + (P_{z_d})_F\right]\sin\theta \qquad (3.1)$$

$$(P_y)_G = (L.\ L.\ F.)\left[(P_{y_d})_L + (P_{y_d})_F\right] \qquad (3.2)$$

$$(P_z)_G = (L.\ L.\ F.)\left[(P_{z_d})_L + (P_{z_d})_F\right]\cos\theta \qquad (3.3)$$

$$(M_x)_G = (L.\ L.\ F.)\Big\{21.0\left[(P_{y_d})_L - (P_{y_d})_F\right] + \left[8.5\,(P_{z_d})_L + 4.1\,(P_{z_d})_F + (M_{x_d})_L + (M_{x_d})_F\right]\cos\theta\Big\} \qquad (3.4)$$

$$(M_y)_G = 21.0\,(L.\ L.\ F.)\left[(P_{z_d})_F - (P_{z_d})_L\right]\sin\theta \qquad (3.5)$$

$$(M_z)_G = -(L.\ L.\ F.)\left[8.5\,(P_{z_d})_L + 4.1\,(P_{z_d})_F + (M_{x_d})_L + (M_{x_d})_F\right]\sin\theta \qquad (3.6)$$

K	(lb/in) The axial spring-rate of the duct.
K_θ	(in-lb/deg) The bending spring-rate of the duct.
L_2	(in.) The half length of the centerline of the bellows on the pump side of the fuel duct.
L_1	(in.) The length of the centerline of the fuel duct between the centers of the pump side and stage side bellows.
α_f, α_m	The engine gimbal angles in degrees. α_f is a positive rotation about the axis fixed from canting on the vehicle side of the gimbal $\alpha_f = \alpha_{x_v}$. α_m is a positive rotation about the axis that cants (moves) with respect to the vehicle side of the gimbal $\alpha_m = \alpha_z$.
θ	The angle relating the duct pump end coordinate system with the engine coordinate system in degrees. $\theta = \tan^{-1}\left(\frac{-\sin \alpha_m}{\tan \alpha_f}\right) \quad 0 \leq \theta \leq 360$
γ	The angle between the engine y axis in the neutral position and the engine y axis in the deflected position (cant angle) in degrees $\gamma = (\alpha_f^2 + \alpha_m^2)^{1/2}$
Δ	(in.) The axial displacement of the centerline of the duct. (1) Oxidizer Duct $\Delta_L = .366\ \alpha_f$ (2) Fuel Duct $\Delta_F = .366\ \alpha_f$
Δ_1	(in.) The maximum axial displacement of the centerline duct. (See figure 9-33.)
P	(lb) An applied force.
P_1	(lb) The applied force necessary to deflect the unpressurized duct a Δ_1 distance. (See figure 9-33.)
M	(in-lb) An applied Moment.
p	(psig) The pressure in the duct.
x, y, z	The engine coordinate system.
x_d, y_d, z_d	The duct coordinate system.
L. L. F.	The limit load factor used in calculating the duct limit loads, L. L. F. = 1.2.

NOTE: The point at which the loads are acting is defined by the following subscripts where:

L refers to the oxidizer pump inlet line.

F refers to the fuel pump inlet line.

G refers to the gimbal center.

Figure 9-30. Definition of Terminology

9-54. **INLET DUCT SPRING RATES.** The inlet ducts have nonlinear spring rates. A plot of deflection versus load for a complete cycle of the ducts, from maximum compression to maximum extension, reveals a hysteresis-type relationship. This is due to a yielding of the bellows convolutions after a certain load magnitude and a resulting increased strain rate for a constant loading rate. Thus, the loads from the inlet ducts are a function of the preceding deflections of the respective ducts.

9-55. The inlet duct bellows are constructed from two different materials: L605 (Haynes 25) and heat-treated Inco 718. Engines not incorporating MD136 change may have either duct; engines incorporating MD136 change have bellows made from heat-treated Inco 718 and are required to meet more stringent spring-rate requirements.

9-56. The ducts with L605 bellows have a hysteresis (load deflection) envelope similar to that shown in figure 9-31. The curve of figure 9-31 was established from axial deflection-tests performed on the individual bellows and is expressed as a function of the dimensionless ratios $\Delta/\Delta 1$ and $p/p1$. The value of Δ_1 and the range of values for P_1 are given for each duct in figure 9-32. This envelope is applicable for the direct deflections resulting from a maximum gimbaling pattern of the engine. The linear slope on the graph of figure 9-31 is usable up through a gimbal angle α_f of five degrees since the majority of the nonlinearity occurs at angles greater than five degrees.

9-57. The Inco 718 bellows have a narrow hysteresis curve (little change in slope); the spring rate of ducts with these bellows (figure 9-32) can therefore be approximated with a linear spring rate. The load contribution of the bellows bending deflections is only a small part of the overall loads at the gimbal center, therefore, only linear-bending spring rates for all ducts are furnished in figure 9-32.

9-58. **SAMPLE PROBLEM.** The maximum range of inlet duct loads at the gimbal center, for a particular range of duct pressures, will be calculated to demonstrate the use of the equations.

9-59. The loads are presented in figures 9-33 and 9-34 as a function of the engine gimbal angles. These loads were calculated using a computer program to solve the equations. The constant input data, which is printed at the top of figures 9-33 and 9-34, includes the maximum axial spring rates and bending spring from figure 9-32 for a duct with an Inco 718 bellows. The pressure range selected was arbitrary. The two left-hand columns of the printout specify the gimbal angles for which the loads were calculated. They are specified twice for a given position in order to calculate the loads for the full range of duct pressures. The duct pressures used for each case are presented in columns 5 and 6.

9-60. The moments M_{x_G} and M_{z_G} must be overcome directly by the actuators. M_{y_G}, due to the twist, contributes two additional moments, M_{xy} and M_{zy}, about the X and Z axes, respectively. They are a function of the geometry of the gimbal bearing and the coefficient of friction μ between its moving parts. Refer to figure 9-10 for gimbal positions. The moment equations are:

$$M_{xy} = \pm M_{y_G} (0.257\mu) - M_{y_G} \sin \alpha_m$$

$$M_{zy} = \pm \mu M_{y_G}$$

The influence of the change in the maximum duct spring rates, between engines J-2025 and J-2055, on the maximum actuator loads can be demonstrated by the following approximate analysis:

NOTE

> The influence on the M_{y_G} on the actuator loads is small and will be neglected.

Let F = maximum actuator-load magnitude based upon the nominal distance to the actuator attach point.

$$F = \frac{M_{x_G} \pm M_{z_G}}{10.8}$$

The maximum actuator loads, used in this formula and the loads calculated in the sample problem, are presented in figure 9-35.

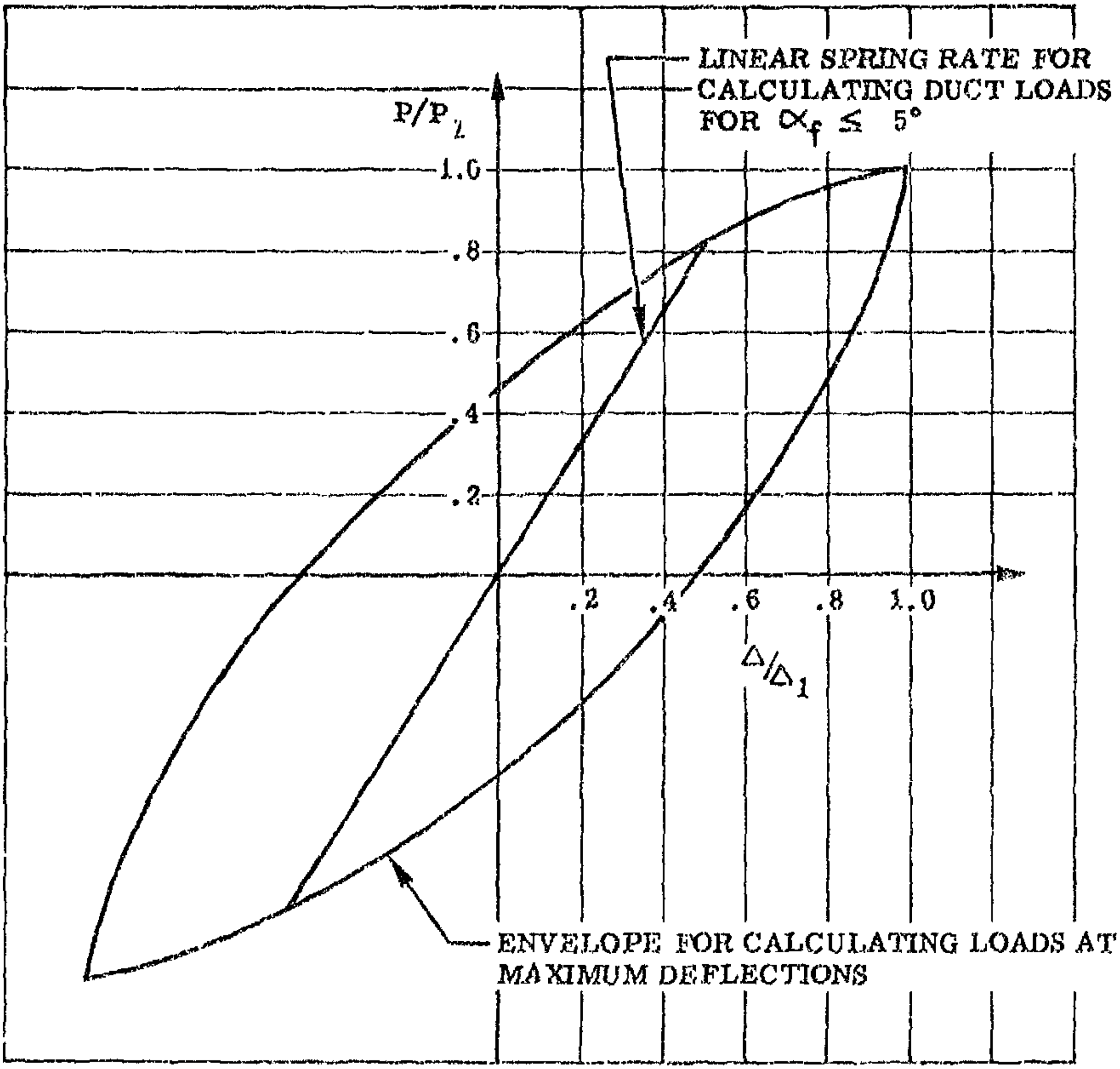

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Figure 9-31. Hysteresis Curve for Inlet Duct With L605 Bellows

	ENGINES J-2025 THROUGH J-2054		ENGINES J-2055 AND SUBSEQUENT	
	Oxidizer Duct	Fuel Duct	Oxidizer Duct	Fuel Duct
1. Inlet ducts with L605 bellows (figure 9-31)				
Δ_1 (in)	±3.75	±3.75	---	---
P_1 (lb)	1,610 to 925	1,690 to 950	---	---
2. Inlet ducts with Inco 718 bellows				
Axial spring rate, K (lb/in)	250 to 435	320 to 480	200 to 270	270 to 390
3. Bending spring rate. K_θ $\frac{\text{(in-lb)}}{\text{deg.}}$	149	275	92	134

Figure 9-32. Inlet Duct Spring-Rate Parameters

9-61. HYDRAULIC SYSTEM INSTALLATION.

9-62. ACCESSORY DRIVE PAD. An accessory drive pad is located on the turbine exhaust manifold of the oxidizer turbopump. The accessory is to be connected directly to the turbine shaft by means of a Rocketdyne-provided quill. The quill requires a female spline on the accessory. No bearings or seals are supplied for the accessory pad. Refer to Rocketdyne blueprint 106475 (customer connect interface) for interface dimensional requirements. See figure 9-36 for spline data.

9-63. A component installed on the accessory drive pad will be subjected to a wide variance of temperature and pressure since the turbine manifold may experience a temperature range from -200° to +900° F. Internal turbine manifold pressure, consisting of hydrogen-rich steam, will range from ambient to a maximum of 56 psia.

9-64. The rotational speed of the accessory drive pad is 7,000 to 9,000 rpm during mainstage with the rotation clockwise viewing the engine drive pad. The engine is delivered with the accessory pad blanked off and the quill shaft packaged separately.

9-65. If hydraulic power is selected, it is assumed that peak loads in the hydraulic system will be absorbed by a properly sized vehicle system accumulator. The estimated oxidizer pump speed buildup during the engine start transient is presented in section VIII. The following limits of drive pad capabilities must be observed:

a. Maximum weight, 25 pounds.

b. Maximum overhung moment, 125 in-lb.

c. Maximum starting torque, 700 in-lb.

d. Maximum continuous running torque, 225 in-lb.

e. Maximum shear design point: The shaft of the accessory mounted on the pad must have a shear design point not to exceed 1,600 in-lb.

f. Allowable eccentricity: The allowable eccentricity between the hydraulic pump centerline and the centerline of the mounting pad is 0.015 inch.

g. Maximum angular misalinement: The maximum angular misalinement between the hydraulic pump shaft centerline and the hydraulic pump mounting pad face is 20 minutes.

9-66. QUILL SHAFT. The length of the quill shaft supplied with the engine is 10.045 inches.

9-67. HYDRAULIC BRACKET LOADS. The hydraulic line support bracket has an allowable limit load capability of 100 pounds axial load and a 100 in-lb moment acting in any direction simultaneously.

		LOX DUCT			LH2 DUCT	
AXIAL SPRING RATE	KL	435.0	LB/IN	KF	480.0	LB/IN
BENDING SPRING RATE	KTHETA	149.0	IN-LB/DEG	KTHETA	275.0	IN-LB/DEG
INTERNAL PRESSURE	P(MAX)	49.0	PSI	P(MAX)	38.0	PSI
	P(MIN)	42.0	PSI	P(MIN)	33.0	PSI

BIPOD FRICTION LOAD	F(D)	250.0	LB
LIMIT LOAD FACTOR	LLF	1.2	
	N	12.	

α_f	α_m	θ	γ									
ALFA(F) (DEG)	ALFA(M) (DEG)	THETA (DEG)	GAMMA (DEG)	P(L) (PSI)	P(F) (PSI)	(PX)G (LB)	(PY)G (LB)	(PZ)G (LB)	(MX)G (IN-LB)	(MY)G (IN-LB)	(MZ)G (IN-LB)	POS
0.001	0.001	-45.000	0.001	49.	33.	0.	6068.	-0.	51424.	-1.	-1.	1
0.001	0.001	-45.000	0.001	42.	38.	0.	5984.	-0.	-20194.	0.	-1.	1
10.700	0.000	-0.000	10.700	49.	33.	0.	6230.	-553.	-46894.	0.	-0.	2
10.700	0.000	-0.000	10.700	42.	38.	0.	6196.	-684.	-117067.	0.	-0.	2
5.300	5.300	-44.877	7.495	49.	33.	236.	6173.	-237.	3320.	-1333.	-3371.	3
5.300	5.300	-44.877	7.495	42.	38.	299.	6089.	-300.	-68130.	3368.	-3204.	3
0.000	10.700	-90.000	10.700	49.	33.	403.	6068.	-0.	51433.	-8242.	-6902.	4
0.000	10.700	-90.000	10.700	42.	38.	527.	5984.	-0.	-20185.	1210.	-6478.	4
-5.300	5.300	-135.123	7.495	49.	33.	162.	5964.	163.	99673.	-6318.	-3497.	5
-5.300	5.300	-135.123	7.495	42.	38.	222.	5880.	223.	27803.	-2171.	-3246.	5
-10.700	0.000	180.000	10.700	49.	33.	-0.	5857.	250.	149077.	0.	0.	6
-10.700	0.000	180.000	10.700	42.	38.	-0.	5773.	370.	76871.	0.	0.	6
-5.300	-5.300	135.123	7.495	49.	33.	-162.	5964.	163.	99673.	6318.	3497.	7
-5.300	-5.300	135.123	7.495	42.	38.	-222.	5880.	223.	27803.	2171.	3246.	7
0.000	-10.700	90.000	10.700	49.	33.	-403.	6068.	-0.	51433.	8242.	6902.	8
0.000	-10.700	90.000	10.700	42.	38.	-527.	5984.	-0.	-20185.	-1210.	6478.	8
5 300	-5.300	44.877	7.495	49.	33.	-236.	6173.	-237.	3320.	1333.	3371.	9
5.300	-5 300	44.877	7.495	42.	38.	-299.	6089.	-300.	-68130.	-3368.	3204.	9
-7.500	0.000	180.000	7.500	49.	33.	-0.	5920.	208.	119755.	0.	0.	10
-7.500	0.000	180.000	7.500	42.	38.	-0.	5836.	292.	47730.	0.	0.	10
-5.000	0.000	180.000	5.000	49.	33.	-0.	5970.	155.	96929.	0.	0.	11
-5.000	0.000	180.000	5.000	42.	38.	-0.	5886	212.	25077.	0.	0.	11
-2.500	0.000	180.000	2.500	49.	33.	-0.	6019.	86.	74160.	0.	0.	12
-2.500	0.000	180.000	2.500	42	38.	-0.	5935.	114.	2434.	0.	0.	12

Figure 9-33. Inlet Duct Loads at the Gimbal Center (Typical Printout) (Engines J-2025 Through J-2054)

```
                                          LOX DUCT                                                        LH2 DUCT
AXIAL SPRING RATE            KL             270.0     LB/IN                      KF              390.0      LB/IN
BENDING SPRING RATE          KTHETA          92.0     IN-LB/DEG                  KTHETA          134.0      IN-LB/DEG
                             P(MAX)          49.0     PSI                        P(MAX)           38.0      PSI
       INTERNAL
       PRESSURE              P(MIN)          42.0     PSI                        P(MIN)           33.0      PSI

                                   BIPOD FRICTION LOAD   F(D)    250.0   LB
                                   LIMIT LOAD FACTOR     LLF       1.2
                                                         N        12.
   α_f       α_m        θ          γ
 ALFA(F)   ALFA(M)    THETA      GAMMA     P(L)        P(F)    (PX)G      (PY)G    (PZ)G     (MX)G     (MY)G     (MZ)G      POS
  (DEG)     (DEG)     (DEG)      (DEG)     (PSI)       (PSI)   (LB)       (LB)     (LB)     (IN-LB)   (IN-LB)   (IN-LB)

   0.001     0.001    -45.000     0.001     49.         33         0      6014.      -3.     47571.       -0.       -0.      1
   0.001     0.001    -45.000     0.001     42.         38.        0.     6032.      -1.    -16333         0.       -0.      1
  10.700     0.000     -0.000    10.700     49.         33.        0.     6578     -741.    -22702.        0.       -0.      2
  10.700     0.000     -0.000    10.700     42.         38.        0.     6602.    -371.    -86501.        0.       -0.      2
   5.300     5.300    -44.877     7.495     49.         33.      321.     6294.    -322.     12357.      -38.    -2443.      3
   5.300     5.200    -44.877     7.495     42.         38.      383.     6318.    -385.    -50923.     4169.    -2330.      3
   0.000    10.700    -90.000    10.700     49.         33.      560.     6014.      -0.     47573.    -4468.    -4778.      4
   0.000    10.700    -90.000    10.700     42.         38.      684.     6033.      -0.    -16330.     4048.     4433.      4
  -5.300     5.300   -135.123     7.495     49.         33.      234.     5735.     235.     82175.    -4337.    -2325.      5
  -5.300     5.300   -135.123     7.495     42.         38.      294.     5759.     295.     18060.     -150.    -2117.      5
 -10.700     0.000    180.000    10.700     49.         33.       -0.     5450.     384.    117440.        0.        0.      6
 -10.700     0.000    180.000    10.700     42.         38.       -0.     5475      304.     53005.        0.        0.      6
  -5.300    -5.300    135.123     7.495     49.         33.     -234.     5735.     235.     82175.     4337.     2325.      7
  -5.300    -5.300    135.123     7.495     42.         38.     -294.     5759.     295.     18060.      150.     2117.      7
   0.000   -10.700     90.000    10.700     49.         33.     -560.     6014.      -0.     47578.     4468.     4778.      8
   0.000   -10.700     90.000    10.700     42.         38.     -684.     6038.      -0.    -16330.    -4048.     4433.      8
   5.200    -5.300     44.877     7.495     49.         33.     -321.     6294.    -322.     12357.       38.     2443.      9
   5.300    -5.300     44.877     7.495     42.         38.     -383.     6318.    -385.    -50923.    -4169.     2330.      9
  -7.500     0.000    180.000     7.500     49.         33.       -0.     5619.     306.     96528.        0.        0.     10
  -7.500     0.000    180.000     7.500     42.         38.       -0.     5643.     391.     32304.        0.        0.     10
  -5.000     0.000    180.000     5.000     49.         33.       -0.     5751.     223.     80213.        0.        0.     11
  -5.000     0.000    180.000     5.000     42.         38.       -0.     5775.     280.     16112.        0.        0.     11
  -2.500     0.000    180.000     2.500     49.         33.       -0.     5883.     121.     63901.        0.        0.     12
  -2.500     0.000    180.000     2.500     42.         38.       -0.     5907.     150.       -94        -0.        0.     12
```

Figure 9-34. Inlet Duct Loads at the Gimbal Center (Typical Printout) (Engines J-2055 and Subsequent)

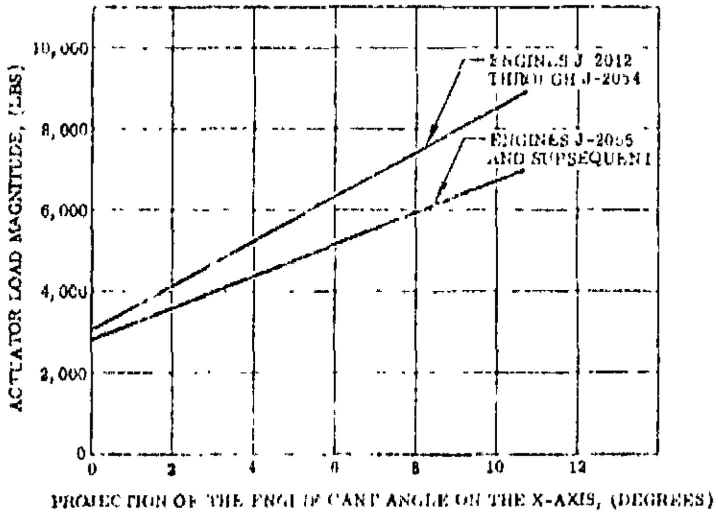


Figure 9-35. Maximum Actuator Loads

Item	Amount	Item	Amount
Number of Teeth	16	Measuring Pin Diameter, inches	0.09600
Diametral Pitch	20/30	Dimension Over 2 Pins (after plating), inches	0.9335, Min. 0.9363, Max.
Pressure Angle, degrees	30	Out of Roundness: Pitch Diameter, inches	0.0011, Max.
Pitch Diameter, inches	0.8000	Lead Error, inches	0.0003, Max.
Base Diameter, inches	0.69282	Tooth to Tooth Spacing Error, inches	0.0001, Max.
Major Diameter, inches	0.863, Min. 0.867, Max.	Accumulated Pitch Error, nonadjustable, inches	0.0015, Max.
Minor Diameter, inches	0.665, Min. 0.670, Max.	Profile Error, inches	0.0005, Max.
Form Diameter, inches	0.727, Max.	Class of Fit	AND 10262
Fillet Radius, inches	0.019, Min.	Type of Fit	Side Fit, Fillet Root
Circular Tooth Thickness (after plating), inches	0.0691, Min. 0.0710, Max.		

Figure 9-36. Accessory Drive Spline Data

Pages 9-47 through 9-60 deleted.

SECTION X

ELECTRICAL SYSTEM INTERFACE DATA

TABLE OF CONTENTS

10-1. SCOPE. This section contains information concerning the engine electrical interface system and the propellant utilization system.

10-2. ELECTRICAL SYSTEM INTERFACE DATA.

10-3. A separate connector is provided to allow component testing and monitoring of the engine controls from GSE. The connector allows pickup of signals for in-flight monitoring of critical control functions and bypass capabilities for simulated sequence testing. To prevent inadvertent sequencing, a component test lock-out is provided. This allows cutoff to be energized from GSE when individual component tests are made. Separate test points allow energization of the control solenoids from GSE. Because the sequencer is designed to provide maximum voltage to the solenoids, there are no protective diodes in series with the feed from the sequencer to the solenoids. Therefore, it is imperative that the voltage used to energize the solenoids from GSE be equal to or less than the engine control voltage, to prevent incorrect current feed into the controller. This criterion should be met by using the component test power connection as a voltage source for energizing solenoids. Refer to figure 10-1 for typical component test power connections.

10-4. Bypass provisions are included in the control system to allow engine sequence testing. Bypass capabilities exist for the following signals: mainstage OK pressure switches, ignition detected (to be used only on engines not incorporating MD338 change), fuel injection temperature OK (for engines not incorporating MD160 or MD204 change, or engines equipped with electrical control assembly (ECA) 502670-11, -111, or -211), and mainstage enable (on engines incorporating MD204 change or equipped with an ECA in the 502670 series with a dash number other than -11, -111, and -211). For flight, the fuel injection temperature circuitry has been replaced by a stage-supplied timer (SIVB) or ECA-controlled mainstage enable signal (SII) to control fuel lead to the engine. The following cutoff circuits are contained in the sequence controller, to protect the engine during start.

a. Ignition detector: On engines not incorporating MD338 change, ignition in the augmented spark igniter (ASI) chamber is monitored by a fusible, wire-link detector probe inserted through the ASI unit into the ASI combustion zone. Engine cutoff will occur if an ignition-complete signal is not received prior to expiration of the ignition-phase timer. Engines requiring restart in flight will be equipped with a dummy ignition detector probe (MD338 change), which will allow engine restart by producing an ignition-complete signal at all times.

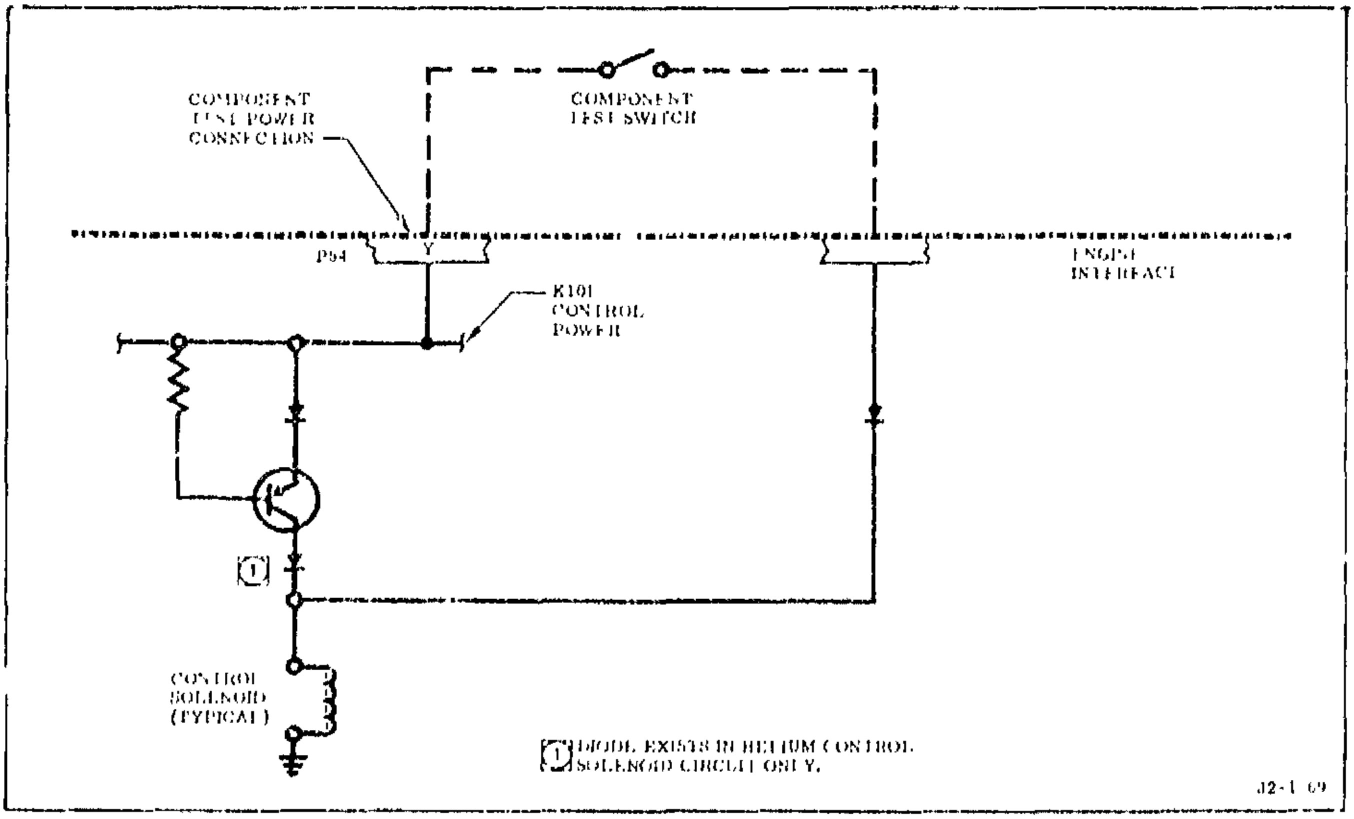


Figure 10-1. Component Test Power Connections (Typical)

b. Mainstage OK pressure switches: Proper mainstage operation is monitored by two mainstage OK pressure switches. These pressure switches must pick up before the deenergization of the spark ignition system or engine cutoff will be initiated. Pickup of either pressure switch will block initiation of cutoff. During engine operation, engine cutoff will be initiated whenever dropout of the switches is caused by deterioration of oxidizer injector pressure. Both switches must drop out for cutoff to be initiated. Pressure switches can be function tested and individually monitored.

10-5. ELECTRICAL CONTROL ASSEMBLY SAFETY PRECAUTIONS.

10-6. The ECA is designed to provide an extremely high degree of reliability. During checkout and operation, the following precautions should be observed to avoid damage to the ECA:

a. The polarity of the power supply to the ECA must never be reversed. The ECA is not protected for reverse polarity.

b. Nonlimited-current output circuits must be protected from overloads or short circuits. This applies particularly to connector P51, pins a, e, b, and Y, and connector P54, pins Y and D.

c. When engine control power buses are energized and an ignition-complete signal is obtained, the ignition detection simulation (electrical connector P54, pin M) must not be energized, since this would result in a redundant ignition-complete signal at the ECA ignition-detection circuitry and may damage the ECA.

d. Extreme caution must be used when troubleshooting the engine electrical system with power applied to the ECA. Accidental momentary shorts or grounds can damage the ECA.

e. During engine checkout and test stand operation, the electrical system must not remain in the mainstage condition for long periods of time. The following conditions are recommended for electrical system mainstage operation:

(1) The ECA internal temperature, if monitored, is limited to 110° F maximum on engines not incorporating MD243 change or not

equipped with ECAs 502670-61, -71, -81, -161, -171, -181, -261, or -271.

(2) If the internal ECA temperature is not monitored and the electrical system is in the mainstage condition for 10 minutes or more, the system should be allowed to cool for 30 minutes before being reenergized.

f. Continuous application of power to the ECA for extended periods of time should be avoided, although the assembly is designed for continuous operation. Because many circuits are in operation at all times, operation of the assembly with power on for days at a time will eventually degrade the reliability of the unit.

g. Proper current loading on certain monitor circuits must be maintained. Due to circuit design, certain monitor circuits supplied through diodes may give faulty recorder operation if not sufficiently loaded down. Due to transistor leakage current, these output diodes may appear as high resistances if the circuit load resistance is too high, and voltage developed may be sufficiently high to actuate sensitive recorders. This applies to connector P51, pins a and Y, and connector P54, pins E, V, and W. (Refer to paragraph 10-16.)

h. Stage or test-stand circuitry must be designed so that either the fuel injection temperature transducer signal or the stage-supplied temperature detector bypass signal is received in proper sequence to provide operation of the spark exciter circuitry within the duty-cycle limitations outlined in paragraph 10-10.

10-7. ELECTRICAL CONTROL ASSEMBLY INTERCHANGEABILITY DATA.

10-8. An ECA of the 502670 part number series can be replaced by an allowable alternate ECA of the same part number series. In some instances the substitution of one ECA for another will affect the electrical interface. To be consistent with the interface effects from an ECA substitution, changes must be made to checkout, static firing, and launch procedures. Interface effects are described in figure 10-2, which lists the ECAs currently in use and the allowable alternates.

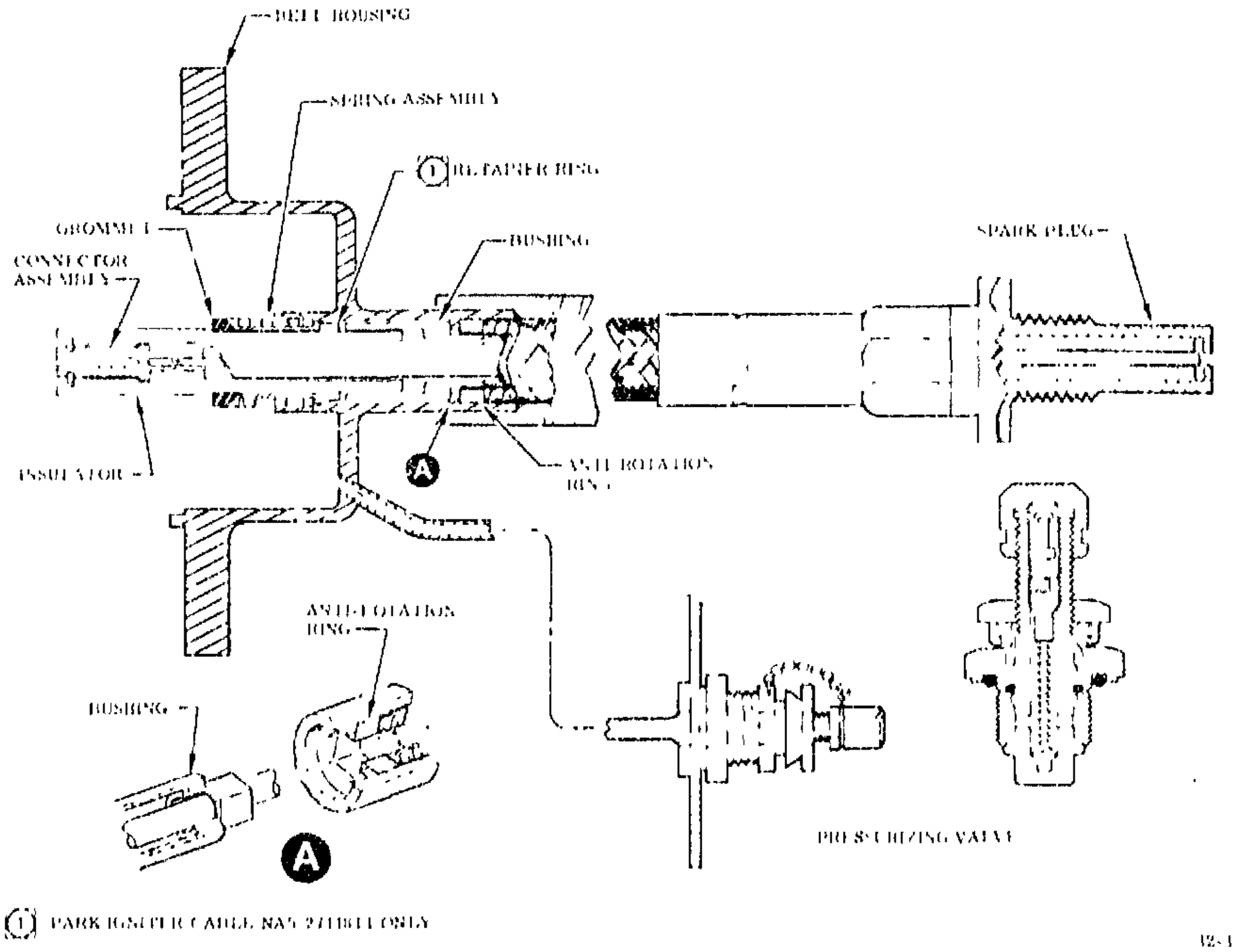
10-9. SPARK IGNITION SYSTEM.

10-10. Ignition is established in the GG and the thrust chamber by the redundant high-tension spark ignition system. The spark exciters transform 28 vdc (nominal) into 27,000 ±3,000 volts, which discharge across the spark plug gap at a minimum rate of 40 sparks per second. A maximum spark rate is not specified because the maximum value is not critical to engine operation. Spark igniter cables (figure 10-1A) transmit the electrical energy from the spark exciters located in the ECA to the spark plugs in the thrust chamber ASI assembly and the GG. The spark igniter cables are pressurized with gaseous nitrogen to prevent breathing of moisture during nonuse and storage environments and to inhibit the possibility of internal glow discharge (corona) during operation at high altitudes. The spark exciters are designed for a duty cycle of 10 seconds on and 5 minutes off, or 5 seconds on and 3 minutes off. The off-time interval must be observed when performing any sequence of engine tests in which the spark igniters are energized, so as not to exceed the recommended duty cycle.

CAUTION

> Component and sequence tests of the engine must be scheduled strictly in accordance with the spark exciter duty cycle above. Exceeding the operating time or repeated operations without the prescribed cooloff time can cause damage to spark exciters and require replacement of the ECA.

10-11. Ground supervision of spark exciter redundancy is accomplished by the observation of four spark monitor signals. These signals are 8 ±2 vdc levels with a 1- to 4-volt pulse superimposed on the dc signal. The pulse frequency is indicative of the rate at which the spark exciter is supplying energy to the spark plug. A typical spark monitor signal is shown in figure 10-3. On engines incorporating MD380 or MD381 change, the multiplex module in the ECA superimposes the redundant timer function on three of the four spark monitor output traces. (See figure 10-3A.) The circuitry allows audible checkout of the spark exciters in pairs (one GG exciter and one ASI exciter). The spark exciter output interval between individual sparks is 25 milliseconds or less. During engine static testing, Spark Monitor/Overspeed Cutoff Panel G1045 monitors the interval between successive sparks and requires that the interval be 25 milliseconds or less throughout the first half-second before giving a spark OK indication.



① SPARK IGNITER CABLE NAS 271B11 ONLY

Figure 10-1A. Spark Igniter Cable Assembly

ECA Part Number(a)	Configuration Change					Replacement F Part Numb
				Engine Effectivity		
	Description of Change	ECP	MD	Retrofit(a)	Production	
502670	Adds second ECA temperature sensor, provision for audible spark igniter component test, and dual monitor capability for mainstage OK pressure switches.	J2-255	187	J-2016 and J-2025		-11 or -111(b
			88		J-2031 through J-2062	-21, -51, -12 or -151(b)
						-61, -71, -81, -161, -171, o -181(b)
502670-11	Changes start tank discharge delay from 0.64 to 1 second.	J2-459	205	J-2026, J-2028, J-2030, J-2035, J-2037, J-2038, J-2040, J-2041, J-2043 through J-2045, J-2047, J-2049 through J-2051, J-2053, J-2055, J-2057 through J-2059, and J-2063 through J-2065	J-2066 through J-2074	-111 or -211 -21, -51, -12 -151, -221, o -251 -61, -71, -81, -161, -171, - -261, or -271
502670-21	Deletes circuit for prechill control (main fuel injection control temperature) and J22 jumper receptacle; deletes start tank pressure switch and sequence control valve position switch circuits.	J2-461	204	J-2036-1, J-2039-1, and J-2073	J-2075 through J-2077	-51, -121, -1 -221, or -251 -61, -71, -81, -161, -171, - -261, or -271
502670-31	Adds improved ignition exciter output adapter and spark exciter bonding.	J2-469	195	J-2037 (made from basic ECA)		None
				J-2073 (also incorporates -21 change configuration)		-61, -161, or -261

(a) Retrofit effectivities for higher ECA dash numbers supersede retrofit effectivities for lower ECA dash numbers.
(b) ECA 502670 (basic configuration) is deleted by creation of -1XX-series part numbers.

Figure 10-2. Electrical Control Assembly Interchangeability Data (Sheet 1 of 3)

-1

e		Allowable Alternate ECAs	
Engine Effectivity		Replacement ECA Part Number	Effects of Replacement
Retrofit[a]	Production		
J-2016 and J-2025	J-2031 through J-2062	-11 or -111[b]	Incorporates 1.000-second start tank discharge delay timer. Compatibility of this change with stage must be evaluated; engines in clusters must have identical timing values.
		-21, -51, -121, or -151[b]	Incorporates 1.000-second timer, and eliminates the following electrical interface functions at connector P54: (Thus, these signals are not obtainable on electrical checkout console.) Fuel injection temperature OK (pin d) Fuel injection temperature simulation (pin S) Start tank depressurized (pin c) Start tank presurized (pin k) Spare monitor (pin N) Changes connector P51, pin X, from Fuel Injection Temperature OK Bypass to Mainstage Enable, and requires signal to enable initiation of start tank discharge after expiration of start tank discharge delay timer
		-61, -71, -81, -161, -171, or -181[b]	Incorporates 1.000-second timer; eliminates functions at P54, pins c, d, k, N, and S; changes connector P51, pin X, to Mainstage Enable; and deletes 110° F ECA internal temperature limitation. (See effects of -21 on basic ECA.)
-2026, J-2028, J-2030, -2035, J-2037, J-2038, -2040, J-2041, J-2043 hrough J-2045, J-2047, -2049 through J-2051, -2053, J-2055, J-2057 hrough J-2059, and -2063 through J-2065	J-2066 through J-2074	-111 or -211	No effect on engine operational requirements.
		-21, -51, -121, -151, -221, or -251	Eliminates electrical functions at P54, pins c, d, k, N, and S, and changes connector P51, pin X, to Mainstage Enable. (See effects of -21 on basic ECA.)
		-61, -71, -81, -161, -171, -181, -261, or -271	Eliminates electrical functions at P54, pins c, d, k, N, and S; changes connector P51, pin X, to Mainstage Enable; and deletes 110° F ECA internal temperature limitation. (See effects of -21 on basic ECA.)
-2036-1, J-2039-1, and -2073	J-2075 through J-2077	-51, -121, -151, -221, or -251	No effect on engine operational requirements.
		-61, -71, -81, -161, -171, -181, -261, or -271	Deletes 110° F ECA internal temperature limitation.
-2037 (made from basic CA)		None	
-2073 (also incorpo- ates -21 change con- guration)		-61, -161, or -261	Deletes 110° F ECA internal temperature limitation.

de retrofit effectivities for lower ECA dash numbers.

1XX-series part numbers.

bility Data (Sheet 1 of 3)

ECA Part Number[a]	Configuration Change					Replacement ECA Part Number
	Description of Change	ECP	MD	Engine Effectivity		
				Retrofit[a]	Production	
502670-51	Adds improved ignition exciter output adapter and spark exciter bonding.	J2-469	195	J-2036-1 and J-2039-1	J-2078 through J-2121	-151 or -251 -61, -71, -81, -161, -171, -181, -261, or -271
502670-61	Eliminates double-soldered terminals, and replaces germanium transistors; deletes 110° F ECA internal temperature limitation.	J2-546 J2-566	243 243	J-2037 and J-2073	J-2122 through J-2130	-71, -81, -161, -171, -181, -261, or -271
502670-71	Requires inspection of solder joints at 20X magnification.	J2-571	239		J-2131 through J-2139	-81, -171, -181, or -271
502670-81	Redesigns wiring for stress relief on component leads.	J2-570	294		None	None
502670-111	Incorporates improved timers in -11 ECAs; incorporates one-second discharge delay timer and improved timers in basic (502670) ECA, thus deleting basic configuration.	J2-606	324	J-2033, J-2036-1, J-2038 through J-2042, J-2044 through J-2067, J-2069 through J-2071, and J-2074		-211 -121, -151, -221, or -251 -161, -171, -181, or -271
502670-121	Incorporates improved timers in ECA -21.	J2-606	324	J-2075 through J-2077		-151, -221, or -251 -161, -171, -181, -261, or -271
502670-151	Incorporates improved timers in ECA -51.	J2-606	324	J-2068 and J-2078 through J-2121		-251 -161, -171, -181, -261, or -271
502670-161	Incorporates improved timers in ECA -61.	J2-606	324	J-2037, J-2073, and J-2122 through J-2130		-171, -181, -261, or -271

(a) Retrofit effectivitites for higher ECA dash numbers supersede retrofit effectivities for lower ECA dash numbers.

Figure 10-2. Electrical Control

ge		Allowable Alternate ECAs	
Engine Effectivity		Replacement ECA Part Number	Effects of Replacement
Retrofit[a]	Production		
J-2036-1 and J-2039-1	J-2078 through J-2121	-151 or -251	No effect on engine operational requirements.
		-61, -71, -81, -161, -171, -181, -261, or -271	Deletes 110° F ECA internal temperature limitation.
J-2037 and J-2073	J-2122 through J-2130	-71, -81, -161, -171, -181, -261, or -271	No effect on engine operational requirements.
	J-2131 through J-2139	-81, -171, -181, or -271	No effect on engine operational requirements.
	None	None	
J-2033, J-2036-1, J-2038 through J-2042, J-2044 through J-2067, J-2069 through J-2071, and J-2074		-211	No effect on engine operational requirements.
		-121, -151, -221, or -251	Eliminates electrical functions at P54, pins c, d, k, N, and S; changes connector P51, pin X, to Mainstage Enable. (See effects of -21 on basic ECA.)
		-161, -171, -181, or -271	Eliminates electrical functions at P54, pins c, d, k, N, and S; changes connector P51, pin X, to Mainstage Enable; and deletes 110° F ECA internal temperature limitation. (See effects of -21 on basic ECA.)
J-2075 through J-2077		-151, -221, or -251	No effect on engine operational requirements.
		-161, -171, -181, -261, or -271	Deletes 110° F ECA internal temperature limitation.
J-2068 and J-2078 through J-2121		-251	No effect on engine operational requirements.
		-161, -171, -181, -261, or -271	Deletes 110° F ECA internal temperature limitation.
J-2037, J-2073, and J-2122 through J-2130		-171, -181, -261, or -271	No effect on engine operational requirements

rsede retrofit effectivities for lower ECA dash numbers.

Figure 10-2. Electrical Control Assembly Interchangeability Data (Sheet 2 of 3)

ECA Part Number[a]	Configuration Change					Replacement E Part Numbe
	Description of Change	ECP	MD	Engine Effectivity		
				Retrofit[a]	Production	
502670-171	Incorporates improved timers.	J2-606	324	J-2131 through J-2139 (made from -71 configuration)	J-2140	-181 or -271
502670-181	Incorporates improved timers (ECP 606); also provides stress relief on component leads and modifies air filler valve. (c)	J2-606	321		J-2145 and subsequent	None
502670-211	Modifies air filler valve on ECA -111.	J2-633	349	J-2036-1, J-2039-1, J-2046, J-2048, J-2049, J-2054, J-2056, J-2060, J-2062 through J-2065, and J-2074		-221 or -251 -181, -261, or -271
502670-221	Modifies air filler valve on ECA -121.	J2-633	349	J-2075 through J-2077		-251 -181, -261, or -271
502670-251	Modifies air filler valve on ECA -151.	J2-633	349	J-2078 through J-2093 and J-2095 through J-2121		-181, -261, or -271
502670-261	Modifies air filler valve on ECA -161.	J2-633	349	J-2037, J-2073, and J-2122 through J-2130		-181 or -271
502670-271	Modifies air filler valve on ECA -171.	J2-633	349	J-2132 through J-2140		-181
			340		J-2141 through J-2144	-181
502670-381	Modifies ECA to improve reliability by eliminating critical single point failure modes associated with timing and ignition detection functions.	J2-706	380	J-2036-1 and subsequent		None
502670-581	Same as -381 except component parts are additionally screened for improved quality.	J2-708	381	J-2036-1 and subsequent		None

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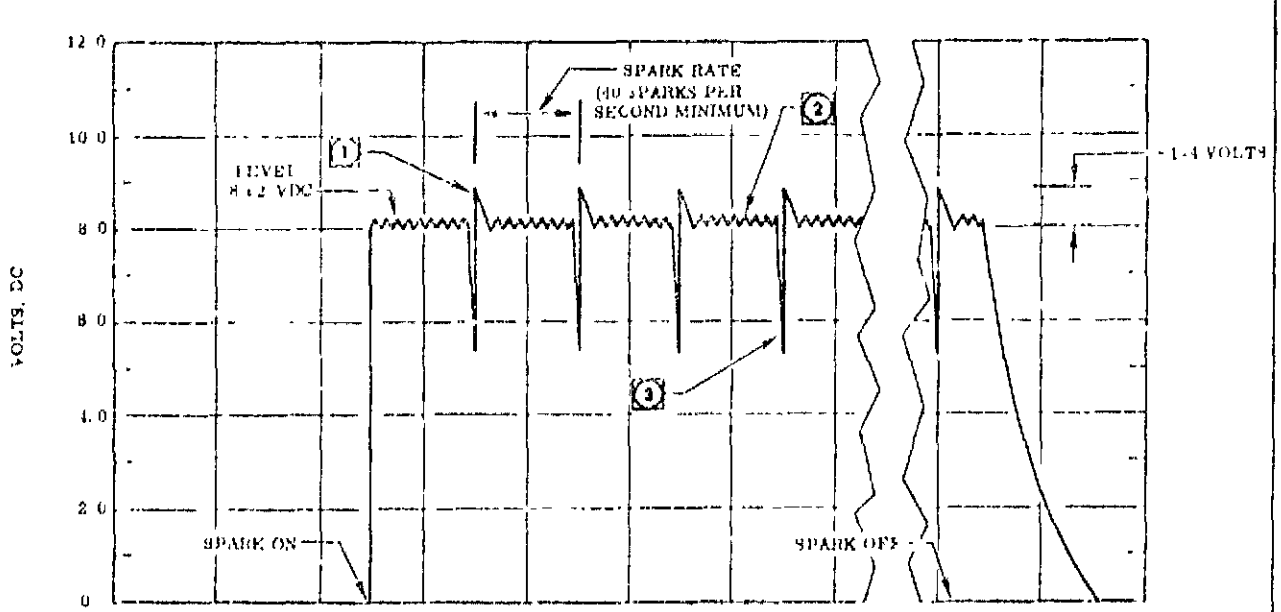
(a) Retrofit effectivities for higher ECA dash numbers supersede retrofit effectivities for lower ECA dash numbers.
(c) Change incorporated in production along with changes described in ECP 570 and ECP 633.

Figure 10-2. Electrical Control Assembly Interchangeability Data (Sheet 3 of 3)

hange			Allowable Alternate ECAs	
	Engine Effectivity			
MD	Retrofit[(a)]	Production	Replacement ECA Part Number	Effects of Replacement
24	J-2131 through J-2139 (made from -71 configuration)	J-2140	-181 or -271	No effect on engine operational requirements.
4		J-2145 and subsequent	None	
9	J-2036-1, J-2039-1, J-2046, J-2048, J-2049, J-2054, J-2056, J-2060, J-2062 through J-2065, and J-2074		-221 or -251	Eliminates electrical functions at P54, pins c, d, k, N, and S; changes connector P51, pin X, to Mainstage Enable. (See effects of -21 on basic ECA.)
			-181, -261, or -271	Eliminates electrical functions at P54, pins c, d, k, N, and S; changes connector P51, pin X, to Mainstage Enable; and deletes 110° F ECA internal temperature limitation. (See effects of -21 on basic ECA.)
9	J-2075 through J-2077		-251	No effect on engine operational requirements.
			-181, -261, or -271	Deletes 110° F ECA internal temperature limitation.
	J-2078 through J-2093 and J-2095 through J-2121		-181, -261, or -271	No effect on engine operational requirements.
	J-2037, J-2073, and J-2122 through J-2130		-181 or -271	No effect on engine operational requirements.
	J-2132 through J-2140		-181	No effect on engine operational requirements.
		J-2141 through J-2144	-181	No effect on engine operational requirements.
	J-2036-1 and subsequent		None	Verification of correct timer operation requires recording of the four spark monitor/timer multiplex signals and the engine cutoff signal when engine electrical sequence tests are performed.
	J-2036-1 and subsequent		None	Verification of correct timer operation requires recording of the four spark monitor/timer multiplex signals and the engine cutoff signal when engine electrical sequence tests are performed.

upersede retrofit effectivities for lower ECA dash numbers.
s described in ECP 570 and ECP 633.

ingeability Data (Sheet 3 of 3)



1 WHEN DETERMINING SPARK RATE, COUNT ONLY PROMINENT POSITIVE SPIKES

2 DISREGARD REDUCED RIPPLES BETWEEN POSITIVE SPIKES; THEY ARE A RESULT OF EXCITER CHARGING CIRCUIT.

3 WHEN DETERMINING DC LEVEL, DISREGARD NEGATIVE SPIKES

J2-1-10

Figure 10-3 Spark Monitor Output (Typical)

10-12. Under certain engine firing conditions, quenching of the spark can occur. Gap, temperature, gas, and pressure parameters determine whether quenching of the spark will occur during engine start. Quenching can be caused by turbine spin and/or pressure buildup during transition in the ASI and GG. The dc level and the spark pips change characteristics if quenching occurs. (See figure 10-3.)

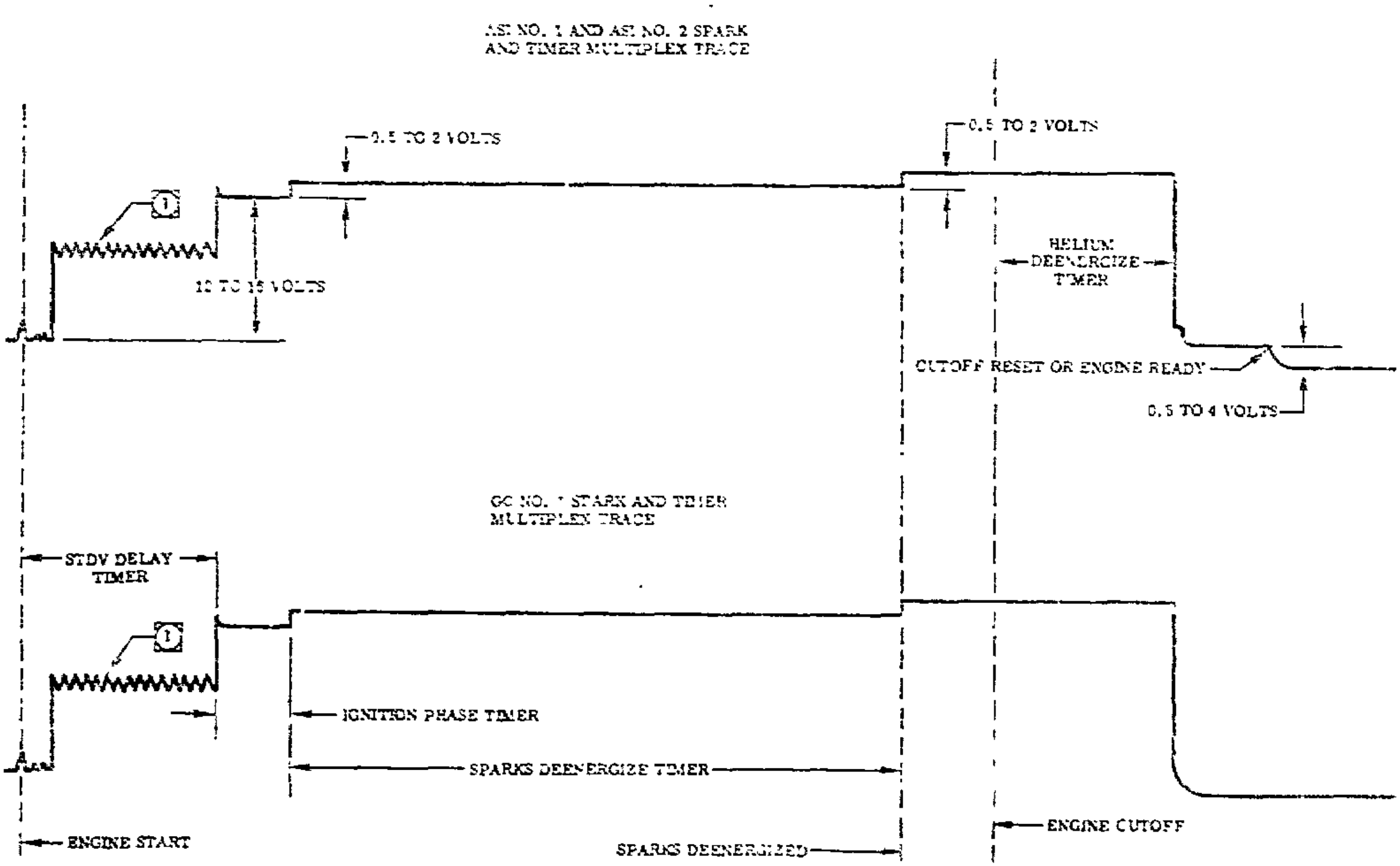
10-13. POWER REQUIREMENTS.

10-14. Separate power supply circuits are provided for control power and ignition power requirements as follows:

a. Control power: 360 watts maximum continuous for electrical control circuits and solenoids during start and powered flight, 24-31 vdc during engine start, and 22-31 vdc after mainstage operation is achieved. (See figure 10-4 for power profile.)

b. Ignition power: 600 watts maximum continuous from start signal to spark deenergized, 24-31 vdc. On engines incorporating MD160 or MD204 change, spark ignition may be required for as long as 12 seconds, depending on setting of stage timer. (See figure 10-4 for power profile.)

10-15. At initial voltage application, the voltage may be 32 vdc maximum for a period not to exceed 60 seconds. The dc peak-ripple voltage must not exceed 2.1 volts when measured by a peak-reading vacuum tube voltmeter in a series with a 4.0-microfarad capacitor. The higher of the two values measured, when the voltmeter is successively connected for each of the two polarities, must be considered the ripple voltage. The maximum voltage transient limit is a 50-volt positive pulse with a time width of 10 microseconds and a repetition rate of 20 pulses per second.



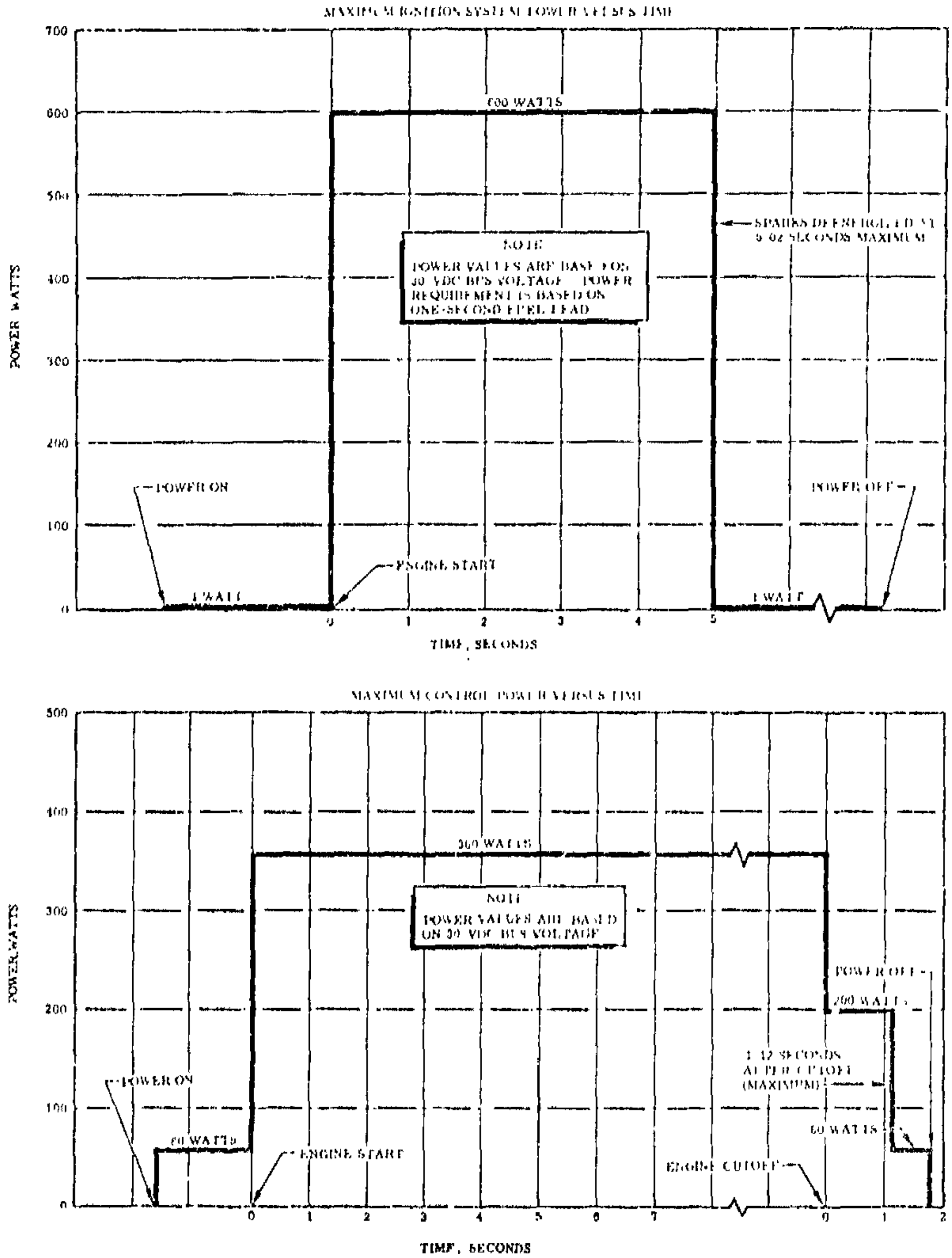
NOTE

DISREGARD PERTURBATIONS WHERE VOLTAGE LEVEL CHANGES OCCUR. VOLTAGE AND TIMER INTERVALS ARE TYPICAL FOR BOTH TRACES AND ARE NOT SHOWN TO SCALE.

① SEE FIGURE 10-3 FOR SPARK TRACE REQUIREMENTS EXCEPT REDUCE VOLTAGE LEVELS BY 1.0 VOLTS

J2-1-150

Figure 10-3A. Spark and Timer Multiplex Output


MAXIMUM IGNITION SYSTEM POWER VERSUS TIME

MAXIMUM CONTROL POWER VERSUS TIME

Figure 10-4. Electrical Control and Ignition System Power Requirements

10-16. The engine electrical system is schematically represented in figure 10-5. The electrical interface connections are shown in figures 10-6 and 10-7. A complete list of the interface connections of connectors P51, P54, and P38 are contained in figures 10-8, 10-9, and 10-10; notes and engine effectivity codes for these figures are contained in figures 10-11 and 10-12. The purpose of connector P51 is to provide power for the electrical control system and the spark ignition system, command signals for engine control, and engine-vehicle interlock functions. The purpose of connector P54 is to provide signals necessary for monitoring and checkout from the ground support equipment, and signals necessary for in flight instrumentation. The purpose of connector P38 is to provide signals necessary to control and monitor the propellant utilization (PU) valve. Relation of minimum monitor output voltage to input voltage and external load resistance is shown in figure 10-13.

10-17. PROPELLANT UTILIZATION SYSTEM.

10-18. The PU valve and its servomotor are supplied with the engine, and a position feedback potentiometer is supplied as a part of the PU valve assembly. The position feedback potentiometer has a resistance of 4,000 ohms. The PU valve assembly and its customer-supplied, stage- or facility-mounted control system make up the PU system. The PU valve has the capability of varying the engine thrust and mixture ratio by regulating the rate of oxidizer circulation through the bypass line from the turbopump volute outlet to the high-pressure side of the turbopump inducer.

10-19. Figure 10-14 shows a schematic of the electromechanical PU valve assembly. The vehicle portion of the system is not represented in the schematic.

NOTE

> To obtain adequate repeatable start transients, it is mandatory that the vehicle maintain the PU valve in the null position until a minimum of 90 percent of engine thrust is attained. During SIVB restarts, the PU valve must be held in the minimum (valve open) PU position until at least 5 seconds after STDV open control signal.

10-20. PROPELLANT UTILIZATION CONTROL SYSTEM CHARACTERISTICS.

10-21. The PU valve electrical power requirements and control system characteristics are as follows:

a. Servomotor fixed phase (SIVB stage): 108-121 vac rms, 394-410 Hz, 35 watts maximum at 121 vac rms and 394 Hz; power factor, 0.39 to 0.70; maximum current, 0.600 ampere rms

b. Servomotor fixed phase (SII stage): 108-121 vac rms, 394-410 Hz, 35 watts maximum a 121 vac rms and 394 Hz; power factor, 0.39 to 0.70. The maximum current is 0.600 ampere rms, and the Stage Contractor must assure that the combination of the five PU valve current values on each stage do not exceed the capability of the PU computer. When a current measurement is obtained with the valve at ambient temperature, use the following relationship to determine the cold valve current:

$$I_{fc} = (R_t - R_1)(0.00859) - 0.106 + I_{fm}$$

where

I_{fc} = cold fixed-phase current (amperes)
R_t = measured control-phase resistance (ohms) at I_{fm} current
R_1 = measured test lead resistance (ohms)
I_{fm} = measured fixed-phase current (amperes)

c. Servomotor control phase: 40 vac rms maximum, 394-410 Hz, 16 watts maximum at 40 vac rms and 394 Hz; power factor, 0.39 to 0.70; maximum current, 0.800 ampere rms (based on not using center tap)

NOTE

> The center tap of the control-phase winding is located 38 turns from either end of the winding, and each half of the control-phase winding must have a dc resistance of 8.2 (±10 percent) ohms at 68° F.

d. Phase relationship (electrical connector P38): For valve closing, fixed-phase voltage on pin R with respect to pin P leads control-phase voltage on pin C with respect to pin E. For valve opening, fixed-phase voltage on pin R with respect to pin P lags control-phase voltage on pin C with respect to pin E.

e. Listed voltages are rms values based on sinusoidal waveforms. One of the applied voltages may be nonsinusoidal. If a nonsinusoidal waveform is applied to the servomotor, the waveform must be passed through a wave analyzer, the fundamental sinusoid must meet the voltage requirements, and the phase relationship applies to the fundamental sinusoid.

f. With the PU valve stalled, the required control-phase voltage must be determined by the following relationship:

$$Vc = \frac{115}{V_f}\left(\frac{V_T + 8.4}{-0.236 + 0.0276\phi - 0.000155\phi^2}\right)$$

where

Vc = control-phase voltage
V_T = measured PU valve maximum threshold voltage
V_f = measured fixed-phase voltage
ϕ = measured-phase relationship in degrees between the fixed-phase voltage and the control-phase voltage with the PU valve stalled

The Stage Contractor establishes whether or not the available computer voltage is greater than the calculated Vc for the PU valve. In the event that the available computer voltage is not greater than the calculated Vc for the PU valve, NASA will determine the required action. The extent of the possible incompatibility is limited by the following:

(1) The available computer voltage ($Vc \sin\phi$) must be a minimum of 15 vac for the PU valve by the above equation.

(2) The required PU valve threshold voltage (V_T) must be a maximum of 15.1 vac. For PU valves tested as a component (not installed on an engine) subsequent to 24 April 1969, the required PU valve threshold voltage (V_T) is a maximum of 12.0 vac.

g. Steps e and f apply at all motor operating temperatures that may vary between +300° F and -50° F as determined by measuring control phase winding resistance. Power must not be applied to the motor if protective covers or insulation is on the valve actuator, except insulation installed by Rocketdyne drawings or modification instructions. Without liquid oxygen in the valve, operation may be programmed concurrently with power on. Prior to loading cryogenics, power must be applied to the fixed phase and the valve positioned to null for 0.50 hours minimum. With the PU valve closed, the resistance between connector P38 (pins J and K) and connectors P105 (pin D) and P107 (pin e) must have minimum resistance. With the PU valve open, the resistance between connector P38 (pins K and L) and connectors P107 (pin e) and P107 (pin E) must have minimum resistance.

h. Valve response: Given a step command, the valve must travel stop-to-stop (60 ±2 degrees) within 2.25 seconds maximum, when the voltage and phase relationship of the expression

$$Vc = \frac{115}{V_f}\left(\frac{V_T + 8.4}{-0.236 + 0.0276\phi - 0.000155\phi^2}\right)$$

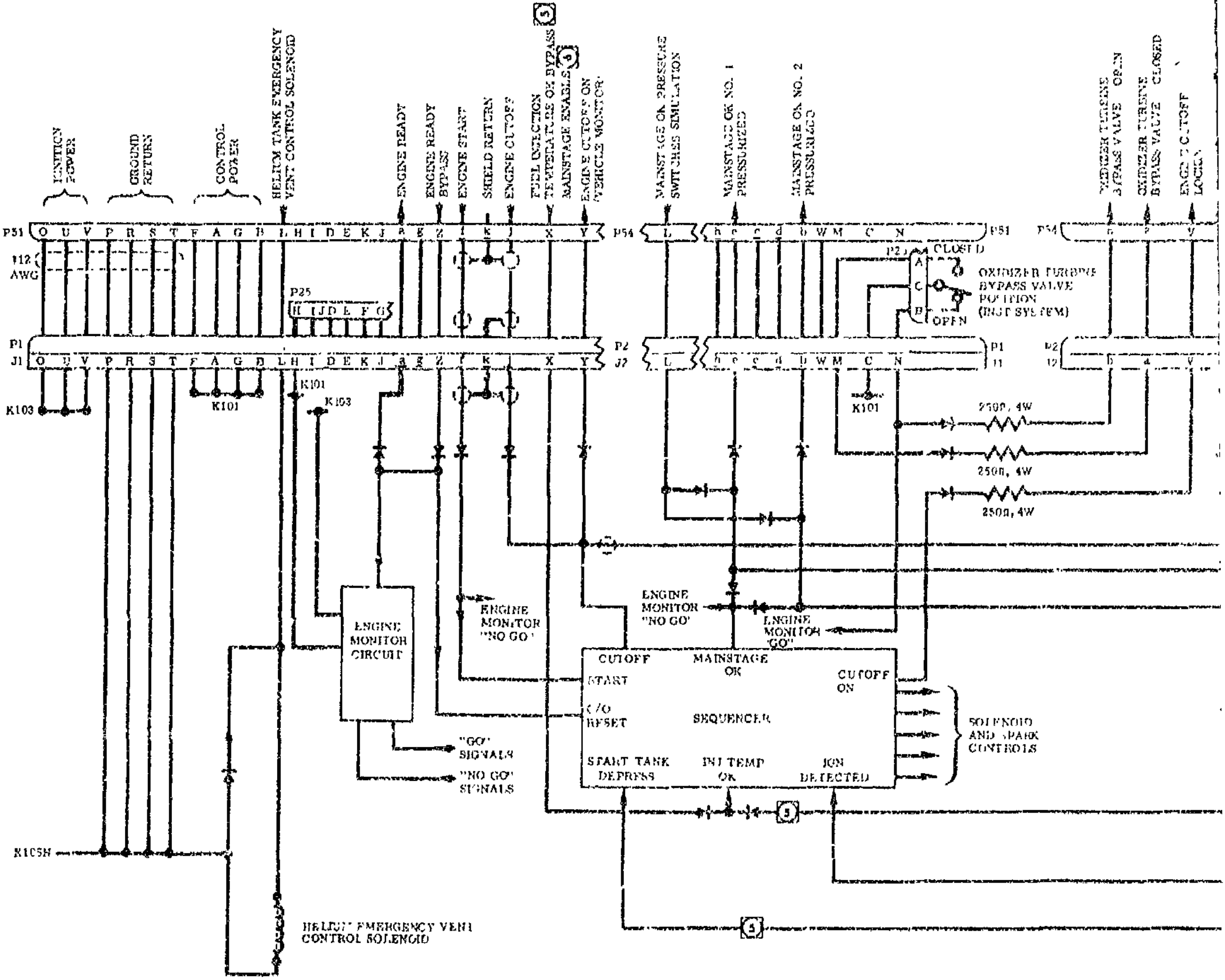
are available if required by the PU valve motor.

i. Feedback potentiometer: Resolution 0.15 percent minimum; linearity ±0.50 percent from best straight line.

j. Gearing backlash:

(1) Power gear train (motor-to-valve gate): with motor pinion gear locked, valve gate assembly backlash must not exceed one degree of arc.

(2) Potentiometer gear train (valve gate to potentiometer), with potentiometer pinion gear locked, valve gate assembly backlash must not exceed 0.50 degree of arc.



① USE P54-Y AS VOLTAGE SOURCE.

② ENERGIZE DURING COMPONENT TESTING.

③ ON ENGINES NOT INCORPORATING MD160 CHANGE (ON ENGINES INCORPORATING MD160 CHANGE, A JUMPER PLUG IS INSTALLED.)

④ ON ENGINES NOT INCORPORATING MD204 CHANGE

⑤ REMOVED ON ENGINES INCORPORATING MD204 CHANGE

⑥ ON ENGINES INCORPORATING MD204 CHANGE

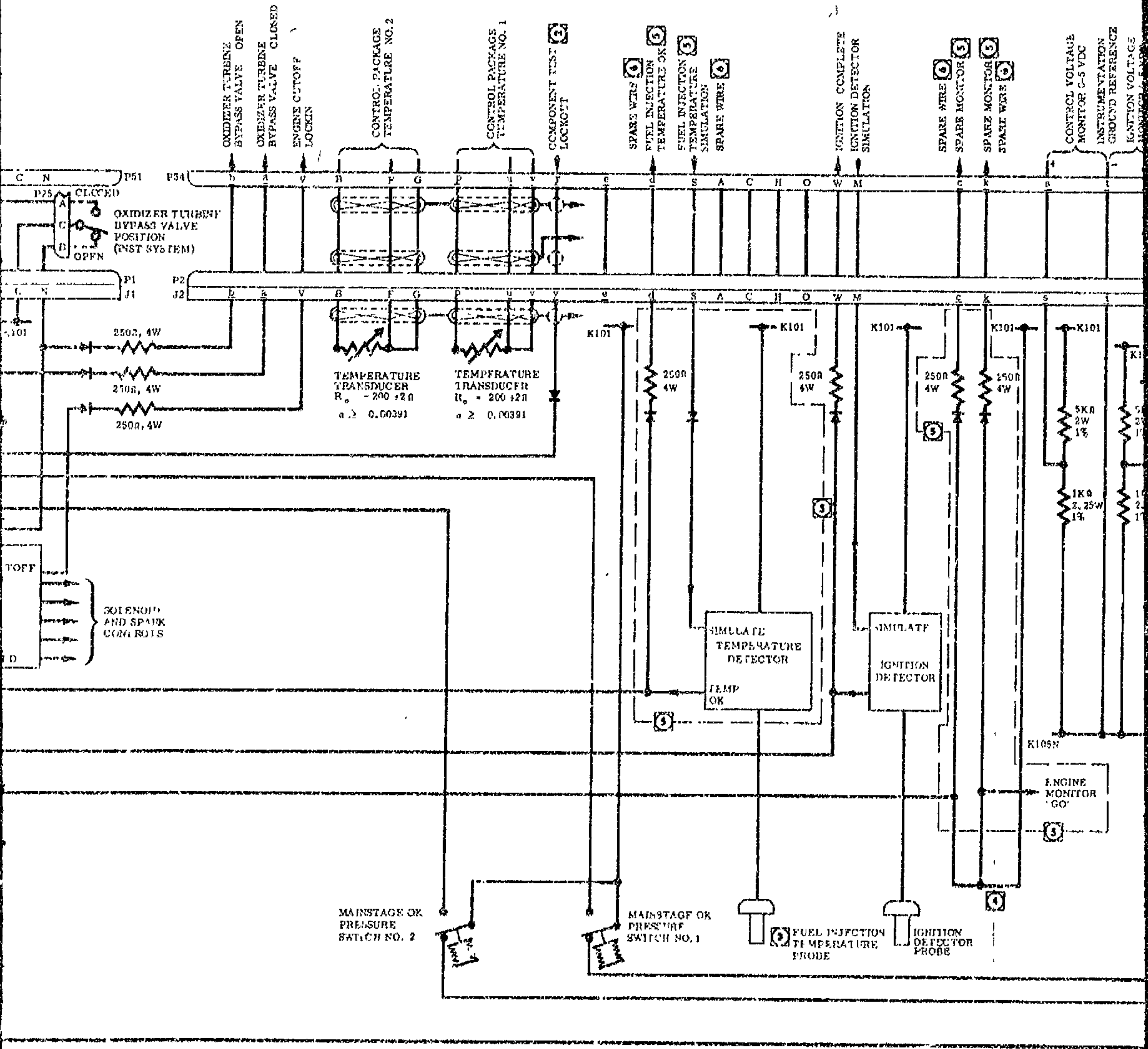

OXIDIZER TURBINE BYPASS VALVE OPEN
OXIDIZER TURBINE BYPASS VALVE CLOSED
ENGINE CUTOFF LOCKIN
CONTROL PACKAGE TEMPERATURE NO. 2
CONTROL PACKAGE TEMPERATURE NO. 1
COMPONENT TEST LOCKOUT 3
SPARE WIRE 6
FUEL INJECTION TEMPERATURE OK 5
FUEL INJECTION TEMPERATURE SIMULATION 5
SPARE WIRE 6
IGNITION COMPLETE
IGNITION DETECTOR SIMULATION
SPARE WIRE 6
SPARE MONITOR 5
SPARE MONITOR 5
SPARE WIRE 6
CONTROL VOLTAGE MONITOR 0-5 VDC
INSTRUMENTATION GROUND REFERENCE
IGNITION VOLTAGE
C N
P51
P54
b a V B F G P u v y e d S A C H O W M c k s t
P25
A
C
B
CLOSED
OPEN
OXIDIZER TURBINE BYPASS VALVE POSITION (INST SYSTEM)
P1
P2
J1
J2
250Ω, 4W
250Ω, 4W
250Ω, 4W
TEMPERATURE TRANSDUCER R_o = 200 ±2 Ω
α ≥ 0.00391
TEMPERATURE TRANSDUCER R_o = 200 ±2 Ω
α ≥ 0.00391
K101
250Ω 4W
5KΩ 2W 1%
1KΩ 2.25W 1%
SIMULATE TEMPERATURE DETECTOR
TEMP OK
SIMULATE IGNITION DETECTOR
5
K105N
ENGINE MONITOR 'GO'
4
TOFF
D
SOLENOID AND SPARK CONTROLS
MAINSTAGE OK PRESSURE SWITCH NO. 2
MAINSTAGE OK PRESSURE SWITCH NO. 1
3 FUEL INJECTION TEMPERATURE PROBE
IGNITION DETECTOR PROBE

Figure 1

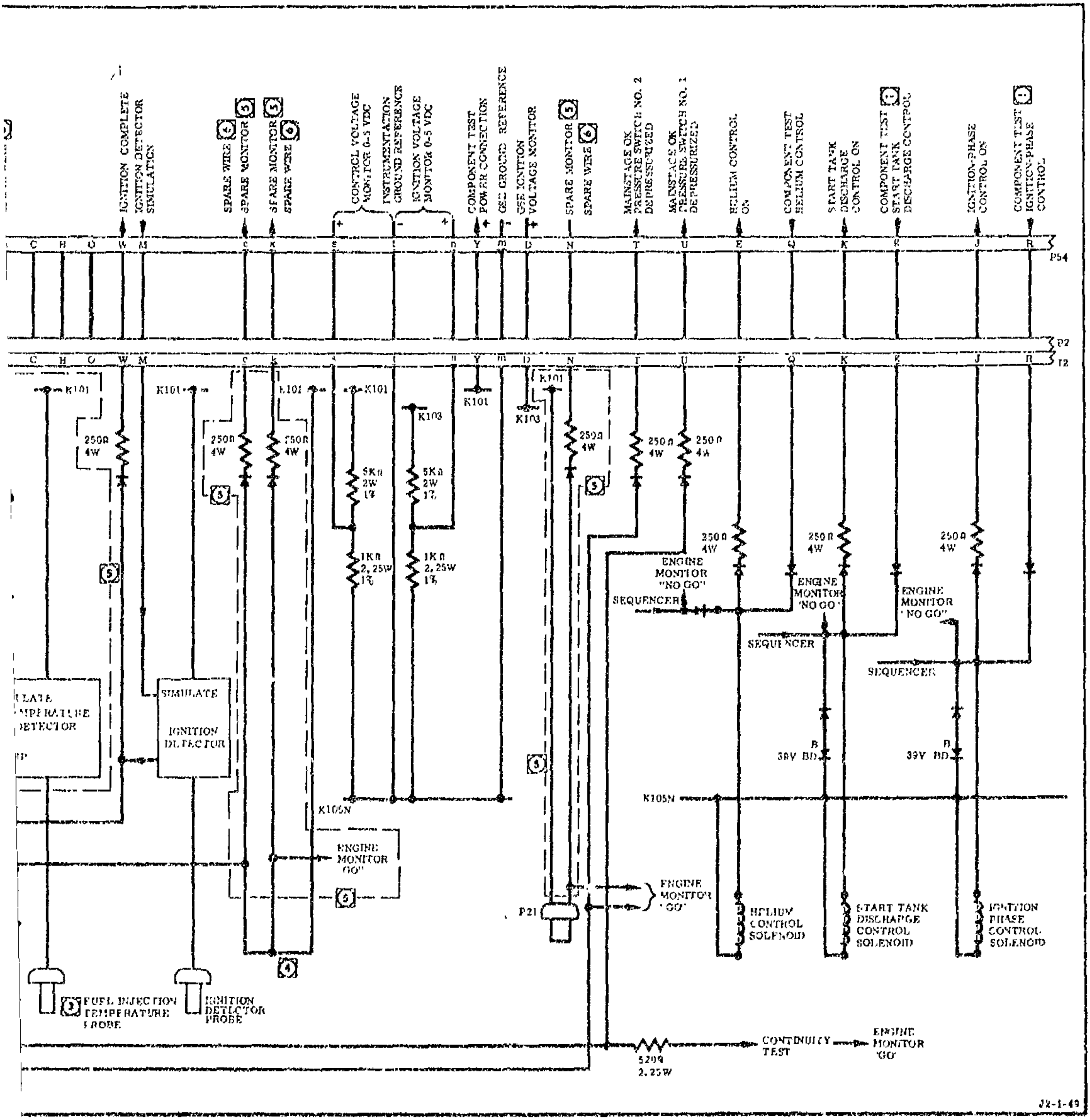


Figure 10-5. Electrical Control System Schematic (Sheet 1 of 2)

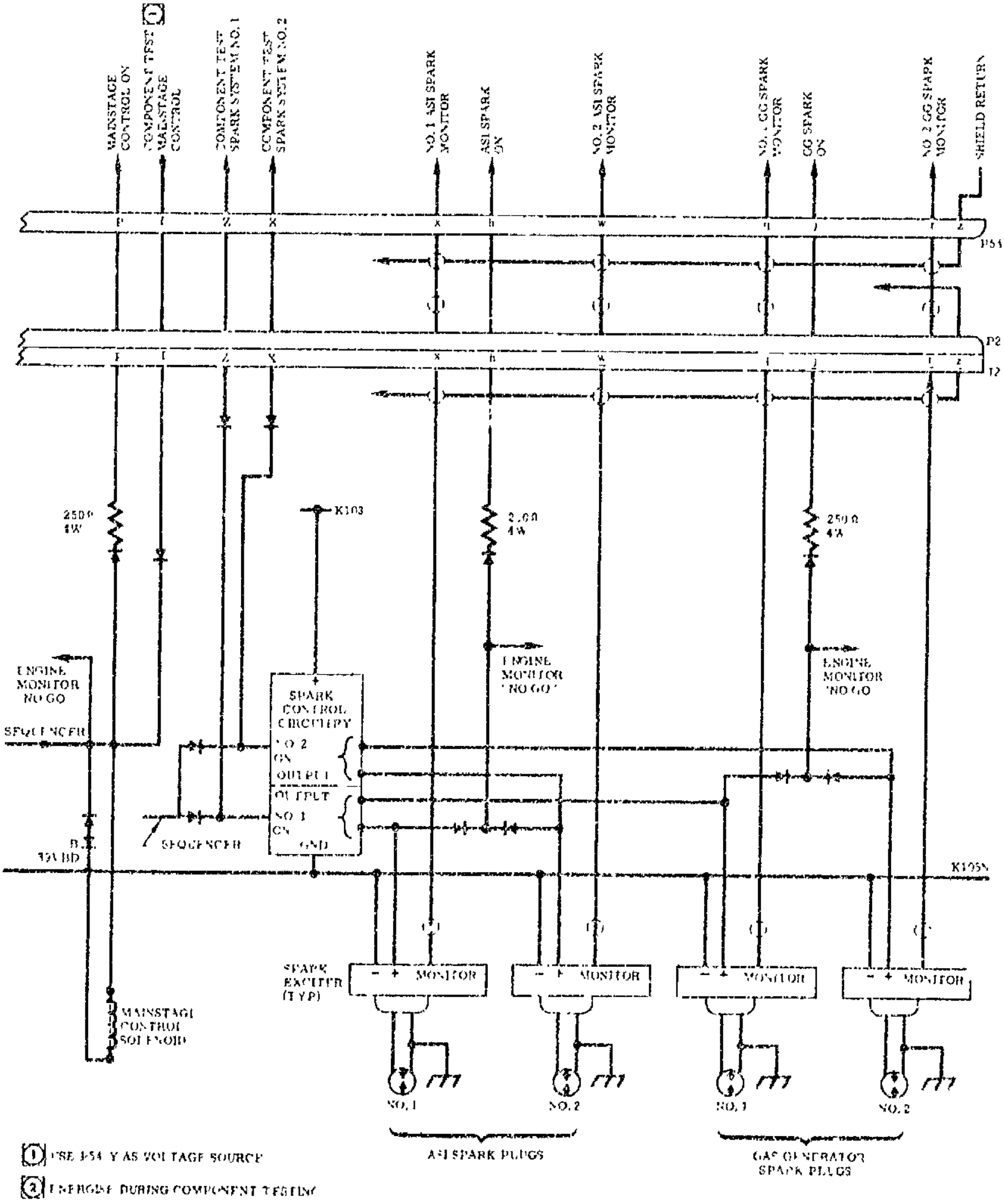
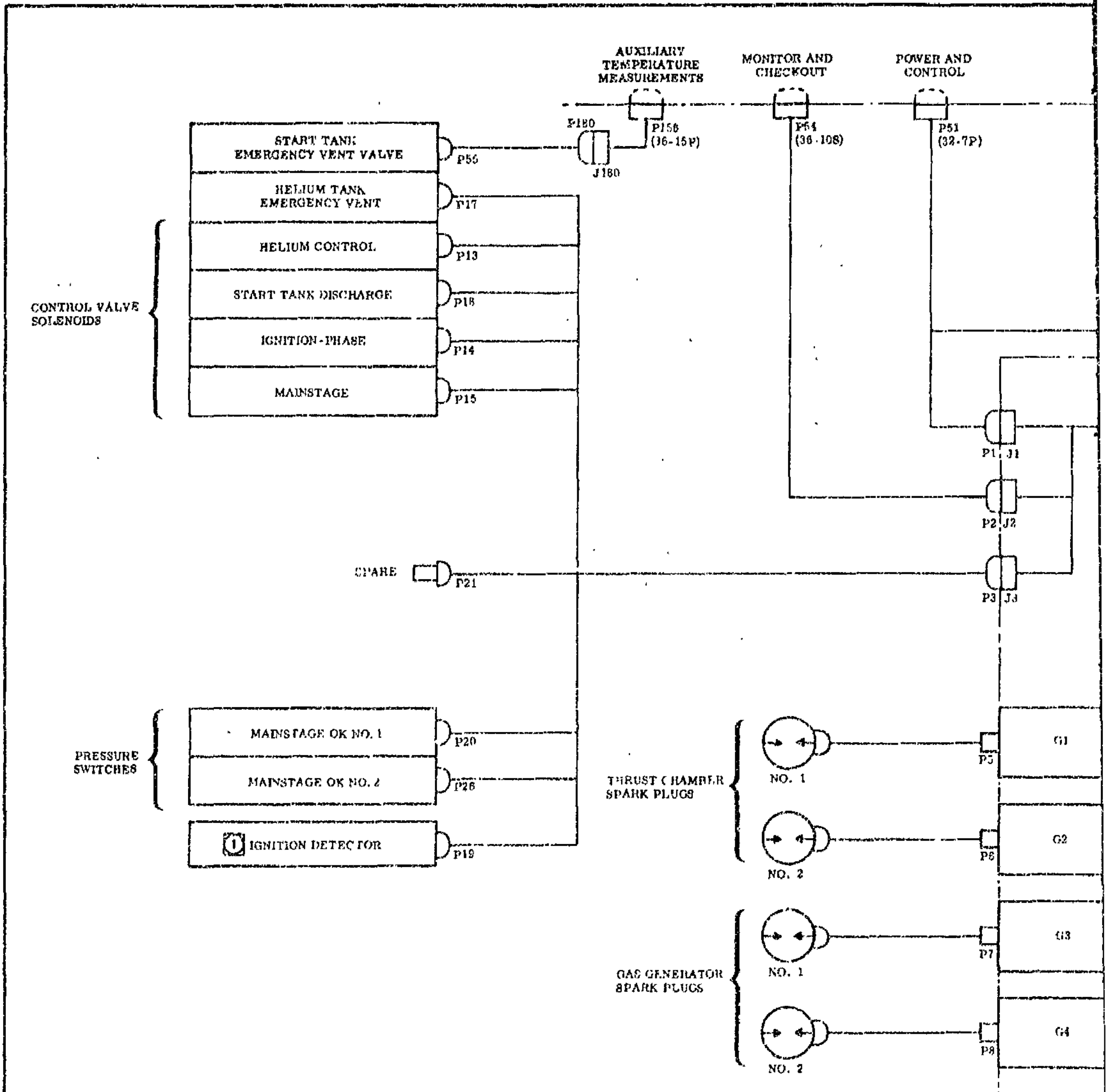


Figure 10-5. Electrical Control System Schematic (Sheet 2 of 2)



1 DUMMY PROBE ON ENGINES INCORPORATING MD338 CHANGE

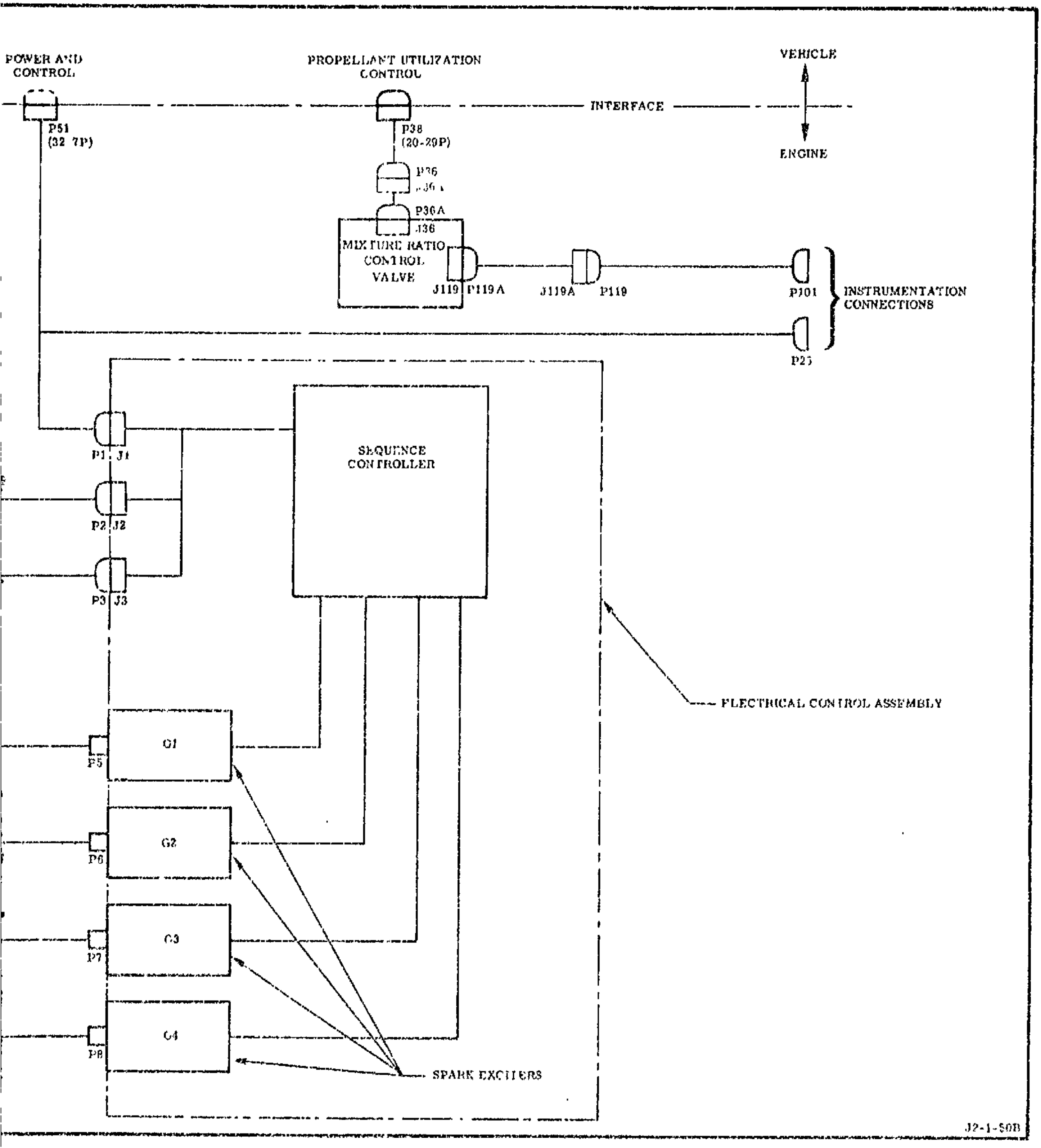


Figure 10-6. Electrical Interface Connections

Interface Connector	Equivalent to	Number of Pins or Sockets	Connector Torque (in-lb)
P38	MS3106-20-29P	17	90-115
P51	MS3106-32-7P	35	140-175
P54	MS3106-36-10S	48	155-165
P105	MS3106-18-1P	10	80-100
P106	MS3106-28-21P	37	130-165
P107	MS3106-28-21S	37	130-165
P108	MS3106-36-8P	47	155-185
P109	MS3106-22-14P	19	100-125
P153	MS3106-22-19P	14	100-125
P154	MS3106-36-10P	48	155-185
P155	MS3106-24-28P	24	115-145
P156	MS3106-36-15P	35	155-185
J110A	MS3100-14S-2P	4	40-60
J111A	MS3100-14S-2P	4	40-50
J160	MS3100-10SL-53P	2	30-40

Figure 10-7. Electrical and Flight Instrumentation Interface Connectors

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
		A	Supply, Control Power	12.0	22-31	(a), (b)
		B	Supply, Control Power	12.0	22-31	(a), (b)
		C	Spare Pin	--	--	
		D	Spare Pin	--	--	
		E	Spare Pin	--	--	
		F	Supply, Control Power	12.0	22-31	(a), (b)
		G	Supply, Control Power	12.0	22-31	(a), (b)
		H	Spare Pin	--	--	
		I	Spare Pin	--	--	
		J	Spare Pin	--	--	
		K	Spare Pin	--	--	
		L	Command, Emergency Helium Vent	3.0	20-31	(a)
		M	Spare Pin	--	--	
		N	Spare Pin	--	--	
		O	Supply, Ignition Power	20.0	22-31	(a), (c)
		P	Return, Ignition and Control Power	32.0	Ground	(d)
		R	Return, Ignition and Control Power	32.0	Ground	(d)

Figure 10-8. Electrical Interface Connector P51 (Sheet 1 of 2)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
		S	Return, Ignition and Control Power	32.0	Ground	(d)
		T	Return, Ignition and Control Power	32.0	Ground	(d)
		U	Supply, Ignition Power	20.0	22-31	(a), (c)
		V	Supply, Ignition Power	20.0	22-31	(a), (c)
		W	Spare Wire	--	--	
	(1)	X	Command, Fuel Injection Temperature OK Bypass	0.03	22-31	(a), (i)
(1)		X	Command, Mainstage Enable	0.03	22-31	(a), (i)
		Y	Measurement, Engine Cutoff ON	0.10	20-31	(e), (f)
		Z	Command, Engine Ready Bypass	0.06	20-31	(a)
		a	Measurement, Engine Ready	0.10	20-31	(e), (f)
	(2)	b	Spare Wire	--	--	
(2)		b	Measurement, Mainstage OK No. 2, Pressurized	0.12	20-31	(e), (f)
		c	Spare Wire	--	--	
		d	Spare Wire	--	--	
	(2)	e	Mainstage OK	--	--	(f)
(2)		e	Measurement, Mainstage OK No. 1, Pressurized	0.12	20-31	(e), (f)
		f	Command, Engine Start	0.10	24-31	(a). Signal required for 20 ms minimum, turn off prior to engine cutoff.
		g	Spare Wire	--	--	
		h	Spare Wire	--	--	
		j	Command, Engine Cutoff	0.30	24-31	(a), Signal required for 20 ms minimum.
		k	Shield Return	Electrostatic Shielding Current	Ground Potential	Connect to common grounding point in stage system.

Figure 10-8. Electrical Interface Connector P51 (Sheet 2 of 2)

Code						
Add	Delete	Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
		A	Spare Wire	--	--	
	(2)	B	Spare Wire	--	--	
(2)		B	Measurement, Control Assembly Temperature No. 2	0.0015	--	See figure 11-19.
		C	Spare Wire	--	--	
		D	Measurement, GSE Ignition Bus Monitor	0.003	24-31	(f)
		E	Measurement, Helium Control ON	0.12	--	(g)
	(2)	F	Spare Wire	--	--	
(2)		F	Measurement, Control Assembly Temperature No. 2	(h)	--	See figure 11-19.
	(2)	G	Spare Wire	--	--	
(2)		G	Measurement, Control Assembly Temperature No. 2	(h)	--	See figure 11-19.
		H	Spare Wire	--	--	
		J	Measurement, Ignition Phase Control ON	0.12	--	(g)
		K	Measurement, Start Tank Discharge Control ON	0.12	--	(g)
		L	Command, Sequence Test, Simulation of Mainstage OK Pressure Switches	0.26	22-31	(a)
	(5)	M	Command, Sequence Test, Ignition Detection Simulation	0.03	22-31	(a), (m)
(5)		M	Spare Wire	--	--	
	(1)	N	Measurement, Spare Monitor	0.12	--	(g)
(1)		N	Spare Wire	--	--	
		O	Spare Wire	--	--	
		P	Measurement, Mainstage Control ON	0.12	--	(g)
		Q	Command, Component Test, Helium Control	2.5	20-31	(g)
		R	Command, Component Test, Ignition Phase Control	3.0	20-31	(g), (l)
	(1)	S	Command, Sequence Test, Fuel Injection Temperature Simulation	0.03	22-31	(a), Not functional with fuel injection temperature sensor jumper receptacle installed.
(1)		S	Spare Wire	--	--	

Figure 10-9. Electrical Interface Connector P54 (Sheet 1 of 4)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
		T	Measurement, Mainstage OK No. 2, Depressurized	0.12	--	(g)
		U	Measurement, Mainstage OK No. 1, Depressurized	0.12	--	(g)
		V	Measurement, Engine Cutoff Lockin	0.12	16-22	(g), (j), Under certain conditions of operation (simultaneous application of cutoff and engine ready bypass commands), the leakage current (one milliampere maximum) in the "off" state will develop a voltage in the external measurement circuit. The measurement circuit input resistance should be approximately 5,000 ohms.
	(5)	W	Measurement, Ignition Complete	0.12	--	(g), Indicates continuously with a dummy ignition detector probe installed.
(5)		W	Measurement, Ignition Complete	0.12	--	(g), (n)
	(2)	X	Spare Wire	--	--	
(2)		X	Command, Component Test, Spark System No. 2	0.16	22-31	(a)
		Y	Supply, Component Test Power	9.0	24-31	(a), (f), To be used as the dc supply for component tests.
	(2)	Z	Command, Component Test, Spark System	0.16	22-31	(a)

Figure 10-9. Electrical Interface Connector P54 (Sheet 2 of 4)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
(2)		Z	Command, Component Test, Spark System No. 1	0.16	22-31	(a)
		a	Measurement, Oxidizer Turbine Bypass Valve Closed	0.12	--	(g)
		b	Measurement, Oxidizer Turbine Bypass Valve Open	0.12	--	(g)
	(3)	c	Start Tank Depressurized	0.12	--	(g)
(3)	(1)	c	Measurement, Spare Monitor	0.12	--	(g)
(1)		c	Spare Wire	--	--	
	(1)	d	Measurement, Fuel Injection Temperature OK	0.12	--	(g)
(1)		d	Spare Wire	--	--	
	(2)	e	Mainstage OK	0.12	--	(g)
(2)		e	Spare Wire	--	--	
		f	Command, Component Test, Mainstage Control	3.0	20-31	(a), (l)
		g	Command, Component Test, Start Tank Discharge Control	3.0	20-31	(a), (l)
		h	Measurement, ASI Spark ON	0.12	--	(g)
		j	Measurement, GG Spark ON	0.12	--	(g)
	(3)	k	Start Tank Pressurized	0.12	--	(g)
(3)	(1)	k	Measurement, Spare Monitor	0.12	--	(g)
(1)		k	Spare Wire	--	--	
		m	Supply, GSE Ground Reference	10.0	GND	
		n	Measurement, Ignition Voltage Monitor	0.0003	0-5	Resistance of measuring device must be 100,000 ohms minimum.

Figure 10-9. Electrical Interface Connector P54 (Sheet 3 of 4)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
		p	Measurement, Control Assembly Temperature No. 1	0.0015	--	See figure 11-19.
	(5)	q	Measurement, No. 1 GG Spark Monitor	--	See figure 10-3.	Measuring device resistance is 10,000 ohms ±10%.
(5)		q	Measurement, No. 1 GG Spark Monitor and Timer Multiplex	--	See figure 10-3A.	Measuring device resistance is 10,000 ohms ±10%.
		r	Measurement, No. 2 GG Spark Monitor	--	See figure 10-3.	Measuring device resistance is 10,000 ohms ±10%.
		s	Measurement, Control Voltage Monitor	0.0003	0-5	Resistance of measuring device must be 100,000 ohms minimum.
		t	Measurement, Instrumentation Return	0.001	--	(k)
		u	Measurement, Control Assembly Temperature No. 1	(h)	--	See figure 11-19.
		v	Measurement, Control Assembly Temperature No. 1	(h)	--	See figure 11-19.
	(5)	w	Measurement, No. 2 ASI Spark Monitor	--	See figure 10-3.	Measuring device resistance is 10,000 ohms ±10%.
(5)		w	Measurement, No. 2 ASI Spark Monitor and Timer Multiplex	--	See figure 10-3A.	Measuring device resistance is 10,000 ohms ±10%.
	(5)	x	Measurement, No. 1 ASI Spark Monitor	--	See figure 10-3.	Measuring device resistance is 10,000 ohms ±10%.
(5)		x	Measurement, No. 1 ASI Spark Monitor and Timer Multiplex	--	See figure 10-3A.	Measuring device resistance is 10,000 ohms ±10%.

Figure 10-9. Electrical Interface Connector P54 (Sheet 3 of 4)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
		y	Command, Component Test, Lockout	0.300	24-31	(a), Command signal to be maintained throughout component test.
		z	Shield Return	Electrostatic Shielding Current	Ground Potential	To be connected to common grounding point in stage system.

Figure 10-9. Electrical Interface Connector P54 (Sheet 4 of 4)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
	(4)	A	Spare Wire	--	--	
(4)		A	Return, Mixture Ratio Control Valve	3.0	GND	
	(4)	B	Spare Wire	--	--	
(4)		B	Command, Mixture Ratio Control Valve to Low EMR	3.0	21-31	(a)
	(4)	C	Supply, PU Valve Control Phase Voltage	0.8	Paragraph 10-20.	Voltage measured with respect to connector P38, pin E. (See figure 10-14)
(4)		C	Spare Wire	--	--	
	(4)	D	Supply, PU Valve Control Phase Voltage	NA	Paragraph 10-20.	Center tap
(4)		D	Spare Wire	--	--	
	(4)	E	Supply, PU Valve Control Phase Voltage	0.8	Paragraph 10-20.	Voltage measured with respect to connector P38,pin C. (See figure 10-14.)
(4)		E	Spare Wire	--	--	
		F	Spare Wire	--	--	

Figure 10-10. Electrical Interface Connector P38 (Sheet 1 of 2)

Code		Pin	Functional Description	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete					
	(4)	G	Continuity Check	5.0	--	Continuity jumper to connector P38, pin S. (See figure 10-14.)
(4)		G	Spare Wire	--	--	
	(4)	H	Measurement, Potentiometer Nominal Tap, Feedback	300×10^{-6}	41.5 (maximum)	Voltage measured with respect to connector P38, pin L.
(4)		H	Spare Wire	--	--	
	(4)	J	Measurement, Potentiometer Ground, Feedback	0.022	77.0 (maximum)	Voltage measured with respect to connector P38, pin L.
(4)		J	Spare Wire	--	--	
	(4)	K	Measurement, Potentiometer Output, Feedback	300×10^{-6}	77.0 (maximum)	Voltage measured with respect to connector P38, pin L.
(4)		K	Spare Wire	--	--	
	(4)	L	Measurement, Potentiometer Input, Feedback	0.022	77.0 (maximum)	
(4)		L	Spare Wire	--	--	
		M	Spare Wire	--	--	
		N	Spare Wire	--	--	
	(4)	P	Supply, PU Valve Fixed-Phase Voltage	--	Paragraph 10-20.	Voltage measured with respect to connector P38, pin R.
(4)		P	Spare Wire	--	--	
	(4)	R	Supply, PU Valve Fixed-Phase Voltage	--	Paragraph 10-20.	Voltage measured with respect to connector P38, pin P.
(4)		R	Spare Wire	--	--	
	(4)	S	Continuity Check	5.0	--	Continuity jumper to connector P38, pin G.
(4)		S	Spare Wire	--	--	
	(4)	T	Shield Return	Electrostatic Shielding Current	Ground Potential	To be connected to common grounding point in stage system.
(4)		T	Spare Wire	--	--	

Figure 10-10. Electrical Interface Connector P38 (Sheet 2 of 2)

(a) Twenty four to thirty one vdc at any start prior to mainstage; 22-31 vdc after mainstage; 32 vdc maximum at initial voltage application for a period not to exceed 60 seconds; ripple voltage not to exceed 2.1 volts peak. The maximum voltage transient limits must be a 50-volt positive pulse with a time width of 10 microseconds and a repetition rate of 20 cps.

(b) One of four parallel control voltage supply inputs having an aggregate maximum current demand of 12.0 amperes.

(c) One of three parallel ignition voltage supply inputs having an aggregate maximum current demand of 20.0 amperes.

(d) One of four parallel dc power supply returns having an aggregate maximum current demand of 32.0 amperes.

(e) Voltage output may be somewhat less (2-4 volts) than control bus voltage due to forward voltage drops in diodes and transistors.

(f) Precautions must be taken to protect these circuits from any short circuit or overloading from stage GSE. Overloading of these circuits can result in burnout of the ECA.

(g) Circuit is protected by 250-ohm series resistor; output voltage is a function of input resistance of measuring device. (Figure 10-13.)

(h) The current balance for the three wires of the temperature transducer should be such that the line resistance is not made a significant part of the measurement.

(i) Signal required for 20 milliseconds minimum after the expiration of the STDV delay timer.

(j) Minimum current with the measurement on is 0.005 ampere.

(k) This pin must be isolated from system ground by a resistance of at least 10,000 ohms to keep the measurement current below 0.001 ampere.

(l) Power from connector P54, pin Y, must be used.

(m) On engines not incorporating MD380 or MD381 change, pin M of connector P54 must not be energized when a signal is present on pin W of connector P54. A spent ignition detector probe or a dummy probe (MD338 change) installed constitutes the remaining normal means of producing a signal on pin W of connector P54.

(n) This measurement is connected to the control bus through a 250 ohm resistor and a diode. The title is retained for interface compatibility with previous electrical control assemblies.

Figure 10-11. Notes for Electrical Interface Connectors

Code	Engine Effectivity		ECP	MD	Description of Change
	Production	Retrofit			
(1)	J-2075 and subsequent	--	J2-461	204	Deletion of ECA unused circuitry
(2)	J-2031 and subsequent	J-2025	J2-255	88 187	Redesign of ECA
(3)	J-2032, J-2052 and subsequent	J-2025, J-2027, J-2031, J-2033, J-2037, J-2042, J-2046, J-2048, and J-2049	J2-399	163	Changes to helium and start tanks
		J-2026, J-2028, J-2030, J-2035, J-2038, J-2040, J-2041, J-2043, J-2044, J-2045, J-2050, and J-2051		202	
(4)	--	J-2036-1, J-2039-1, J-2046 and subsequent	J2-689	366 371	Incorporation of two position mixture ratio control valve.
(5)	--	J-2039-1, J-2046 and subsequent	J2-708	380 381	Redesign of ECA.

Figure 10-12. Engine Effectivity for Electrical Interface Connectors

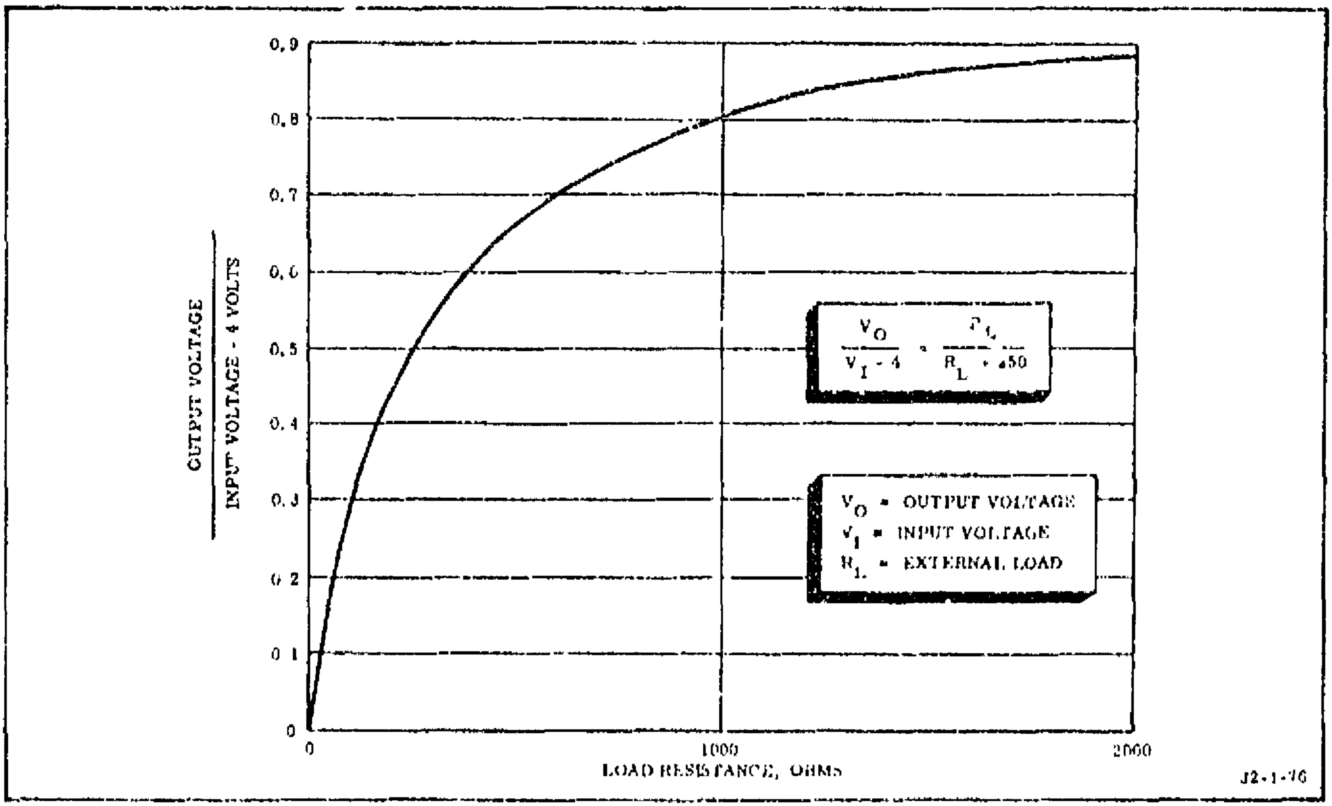


Figure 10-13. Relation of Minimum Monitor Output Voltage to Input Voltage and External-Load Resistance

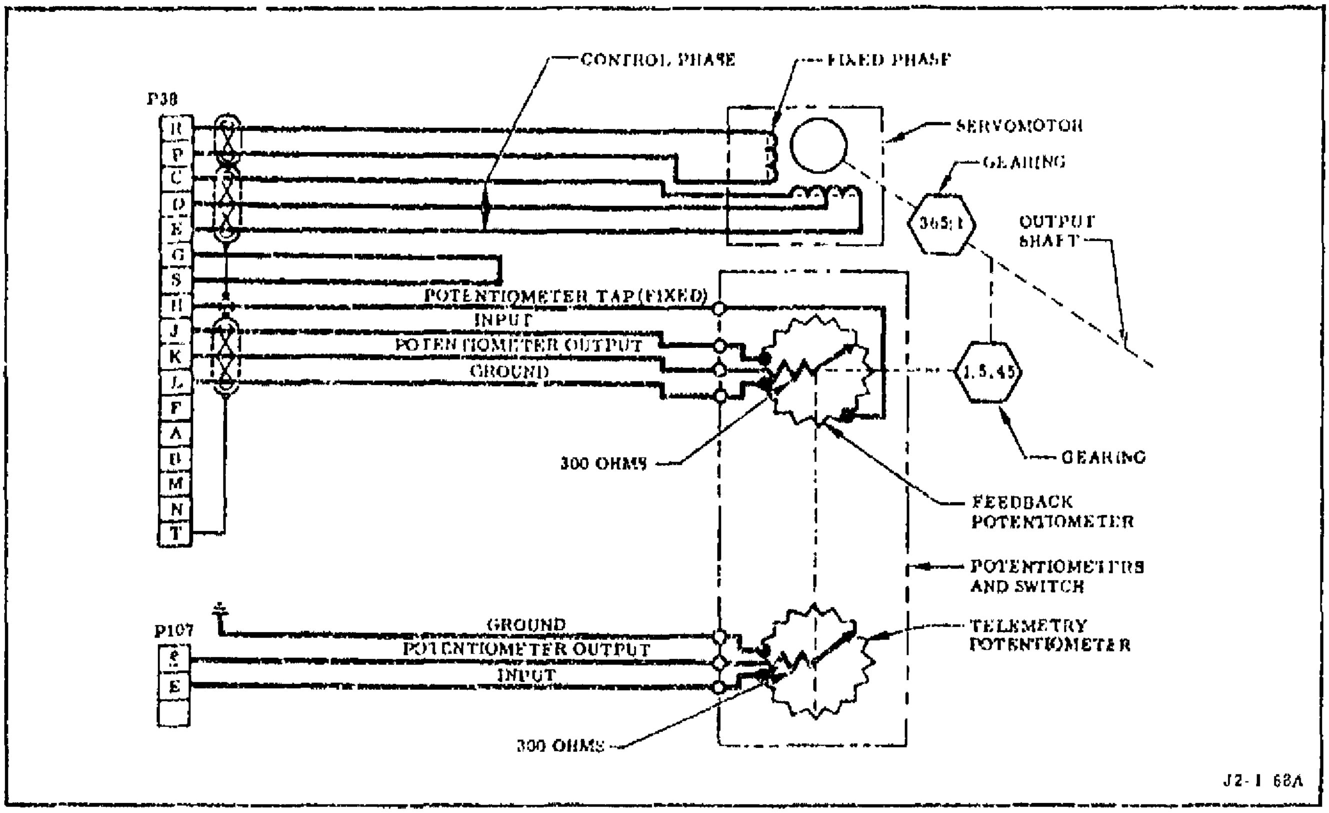


Figure 10-14. Propellant Utilization Control System

SECTION XI

INSTRUMENTATION SYSTEM INTERFACE DATA

TABLE OF CONTENTS

11-1. SCOPE. This section contains interface data for the primary and the auxiliary instrumentation systems.

11-2. INSTRUMENTATION SYSTEM.

11-3. The basic flight instrumentation system is composed of a primary instrumentation system designed to include those parameters critical to all engine static firings and subsequent vehicle launches, and an auxiliary system for use during the research and development and acceptance portion of the engine static-test program and initial vehicle flights.

11-4. The auxiliary package may be deleted from the basic engine instrumentation system after the propulsion system has established its reliability during research and development vehicle flights. Design of the auxiliary package allows for deletion and/or substitution of parameters deemed necessary as a result of additional testing. Eventual deletion of the auxiliary package will not interfere with the reliability of measurement capability of the primary instrumentation system. The primary and auxiliary parameters to be monitored are listed in figures 11-1 through 11-12. Notes and engine effectivity codes for these figures are contained in figures 11-13 and 11-14. Instrumentation tap locations are shown in figure 11-15, and a complete instrumentation list is shown in figure 11-16. The complete engine-to-vehicle electrical and instrumentation interface is presented schematically in figure 11-17.

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete							
		A	Supply, Primary Instrumentation System Package 28 vdc Power	--	--	0.750	24-32	Bussed to connector P106, pin M.
		B	Supply, 28 vdc Duplicate Power Return for Primary Instrumentation System	--	--	1.19	Ground potential	Bussed to connector P106, pin N.
		C	Spare Wire	--	--	--	--	Bussed to connector P106, pin R.
		D	Supply, Primary Instrumentation Package 5 vdc Power Return	--	--	0.1	Ground potential	Bussed to connector P106, pin Z
	(6)	E	Prelaunch Heater Power	--	--	--	--	
(6)		E	Spare Wire	--	--	--	--	
	(6)	F	Prelaunch Heater Return	--	--	--	--	Not used
(6)		F	Spare Wire	--	--	--	--	
	(6)	G	Flight Heater Power	--	--	--	--	
(6)		G	Spare Wire	--	--	--	--	
	(6)	H	Flight Heater Return	--	--	--	--	Not used
(6)		H	Spare Wire	--	--	--	--	
		I	Supply, 28 vdc Common to Valve Switches	--	--	0.5	24-32	
		J	Spare Wire	--	--	--	--	

Figure 11-1. Flight Instrumentation Interface Connector P105

Code		Pin	Functional Description	Range	R_G (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		A	Spare Wire	--	--	--	--	
		B	Spare Wire	--	--	--	--	
		C	Spare Wire	--	--	--	--	
		D	Spare Wire	--	--	--	--	
	(7)(10)	E	Command, Fuel Pump Interstage Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin J; (c)
(7)		E	Spare Wire	--	--	--	--	
(10)		E	Command, Thrust Chamber Low-Range Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin J; (c)
	(7)(10)	F	Command, Fuel Pump Interstage Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin J; (c)
(7)		F	Spare Wire	--	--	--	--	
(10)		F	Command, Thrust Chamber Low-Range Presaure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin J; (c)
		G	Spare Wire	--	--	--	--	
		H	Spare Wire	--	--	--	--	
	(7)(10)	J	Measurement, Fuel Pump Interstage Pressure, Signal Output	0-200 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
(7)		J	Spare Wire	--	--	--	--	

Figure 11-2. Flight Instrumentation Interface Connector P106 (Sheet 1 of 5)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(10)		J	Measurement, Thrust Chamber Low-Range Pressure, Signal Output	0-30 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		K	Measurement, Primary Instrumentation Package Temperature, Signal Output	-300° to +200° F	200 ±2	1.5 x 10^{-3} maximum	--	(d)
		L	Spare Wire	--	--	--	--	
		M	Supply, Primary Instrumentation Package, 28 vdc Power (Redundant)	--	--	0.750 maximum	24-32	Bussed to connector P105, pin A.
		N	Supply, Primary Instrumentation Package, 28 vdc Power Return (Redundant)	--	--	1.19 maximum	Ground potential	Bussed to connector P105, pin B.
		P	Spare Wire	--	--	--	--	
		R	Spare Wire	--	--	--	--	Bussed to pin C.
		S	Measurement, Primary Instrumentation Package Temperature, Output Common	See pin K	See pin K	(f)	Ground potential	
		T	Measurement, Helium Tank Pressure, Signal Output	0-3,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		U	Command, Helium Tank Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin T; (e)
		V	Command, Helium Tank Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin T; (e)

Figure 11-2. Flight Instrumentation Interface Connector P106 (Sheet 2 of 5)

Code								
Add	Delete	Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
		W	Command, Fuel Pump Discharge Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin f; (e)
		X	Command, Fuel Pump Discharge Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin f; (e)
		Z	Supply, Primary Instrumentation Package, 5 vdc Power Return (Redundant)	--	--	0.1 maximum	Ground potential	Bussed to connector P105, pin D.
		a	Measurement, Primary Instrumentation Package Temperature Input Common	See pin K.	See pin K.	(f)	Ground potential	
		b	Measurement, Start Tank Pressure Transducer Signal Output	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		c	Command, Start Tank Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin b; (e)
		d	Command, Start Tank Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin b; (e)
	(4)	e	Measurement, Oxidizer Pump Discharge Pressure, Signal Output	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)

Figure 11-2. Flight Instrumentation Interface Connector P106 (Sheet 3 of 5)

Code		Pin	Functional Description	Range	R_0 (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		f	Measurement, Fuel Pump Discharge Pressure, Signal Output	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		g	Command, Thrust Chamber Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin p; (c)
	(1)	h	Measurement, Gas Generator Chamber Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
(1)		h	Measurement, Fuel Turbine Inlet Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
	(1)	j	Command, Gas Generator Chamber Pressure, 20-Percent Calibration, Voltage	--	--	0.048 maximum	24-32	(a) pin h; (c)
(1)		j	Command, Fuel Turbine Inlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	
		k	Command, Oxidizer Pump Discharge Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin e; (c)
		m	Command, Oxidizer Pump Discharge Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin e; (c)

Figure 11-2. Flight Instrumentation Interface Connector P106 (Sheet 4 of 5)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		n	Command, Thrust Chamber Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin p; (e)
		p	Measurement, Thrust Chamber Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
	(1)	r	Command, Gas Generator Chamber Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin h; (e)
(1)		r	Command, Fuel Turbine Inlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin h; (e)
		s	Shield Return	--	--	Electrostatic shielding current	Ground potential	

Figure 11-2. Flight Instrumentation Interface Connector P106 (Sheet 5 of 5)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes, Maximum)	Volts DC	Remarks/Notes
Add	Delete							
		A	Spare Wire	--	--	--	--	
		B	Spare Wire	--	--	--	--	
		C	Spare Wire	--	--	--	--	
		D	Spare Wire	--	--	--	--	
	(23)	E	Supply, Propellant Utilization Valve Position, Potentiometer, 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)
	(23)	E	Supply, Mixture Ratio Control Valve Position Potentiometer, 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)

Figure 11-3. Flight Instrumentation Interface Connector P107 (Sheet 1 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes Maximum)	Volts DC	Remarks/Notes
Add	Delete							
		F	Spare Wire	--	--	--	--	
		G	Spare Wire	--	--	--	--	
		H	Supply, Start Tank Discharge Valve Position, Potentiometer 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)
		J	Spare Wire	--	--	--	--	
		K	Spare Wire	--	--	--	--	
		L	Spare Wire	--	--	--	--	
		M	Supply, Oxidizer Turbine Bypass Valve Position, Potentiometer 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)
		N	Spare Wire	--	--	--	--	
		P	Spare Wire	--	--	--	--	
		R	Spare Wire	--	--	--	--	
		S	Supply, Gas Generator Valve Position, Potentiometer 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)
		T	Measurement, Fuel Bleed Valve Position Closed	On-Off	--	0.0625	24-32	(l)
		U	Supply, Main Oxidizer Valve Position, Potentiometer 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)
		V	Supply, Main Fuel Valve Position, Potentiometer 5 vdc	--	--	0.003 at 5.0 vdc	5.00 ±0.50	(j)

Figure 11-3. Flight Instrumentation Interface Connector P107 (Sheet 2 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes Maximum)	Volts DC	Remarks/Notes
Add	Delete							
		W	Measurement, ASI Oxidizer Valve Position, Open	On-Off	--	0.0625	24-32	(i)
		X	Measurement, Oxidizer Turbine Bypass Valve Position, Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	(j)
		Z	Measurement, Oxidizer Bleed Valve Position, Closed	On-Off	--	0.0625	24-32	(i)
		a	Measurement, Main Oxidizer Valve Position, Open	On-Off	--	0.0625	24-32	(i)
		b	Measurement, Main Oxidizer Valve Position, Closed	On-Off	--	0.0625	24-32	(i)
		c	Measurement, Start Tank Discharge Valve Position, Open	On-Off	--	0.0625	24-32	(i)
		d	Measurement, Start Tank Discharge Valve Position, Closed	On-off	--	0.0625	24-32	(i)
	(23)	e	Measurement, Propellant Utilization Valve Position Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	
(23)		e	Measurement, Mixture Ratio Control Valve Position Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	
		f	Spare Wire	--	--	--	--	
		g	Measurement, Gas Generator Valve Position, Open	On-Off	--	0.0625	24-32	(i)

Figure 11-3. Flight Instrumentation Interface Connector P107 (Sheet 3 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes Maximum)	Volts DC	Remarks/Notes
Add	Delete							
		h	Measurement, Main Oxidizer Valve Position, Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	(j)
		j	Measurement, Start Tank Discharge Valve Position Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	(j)
		k	Measurement, Main Fuel Valve Position Open	On-Off	--	0.0625	24-32	(i)
		(m)	Measurement, Main Fuel Valve Position, Closed	On-Off	--	0.0625	24-32	(i)
		n	Measurement, Gas Generator Valve Position, Closed	On-Off	--	0.0625	24-32	(i)
		p	Measurement, Gas Generator Valve Position, Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	(i)
		r	Measurement, Main Fuel Valve Position, Potentiometer	Open-Closed	--	5×10^{-5} at 5 vdc	0 to 5.5	(i)
		s	Spare Pin	--	--	--	--	

Figure 11-3. Flight Instrumentation Interface Connector P107 (Sheet 4 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		A	Spare Pin	--	--	--	--	
		B	Spare Pin	--	--	--	--	
		C	Spare Pin	--	--	--	--	
		D	Spare Pin	--	--	--	--	
		F	Spare Pin	--	--	--	--	

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 1 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		F	Spare Pin	--	--	--	--	
		G	Measurement, Start Tank Gas Temperature, "A" Sensor, Sensor Output	-350° to +100° F	1,256 ±6	8.3×10^{-4} maximum	--	(d)
		H	Measurement, Start Tank Gas Temperature, "B" Sensor, Sensor Output	-350° to +100° F	1,256 ±6	8.3×10^{-4} maximum	--	(d)
		I	Measurement, Start Tank Gas Temperature "A" Sensor, Input Common	See pin G.	See pin G.	(f)	Ground potential	
		J	Measurement, Start Tank Gas Temperature, "A" Sensor, Output Common	See pin G.	See pin G.	(f)	Ground potential	
		K	Measurement, Start Tank Gas Temperature, "B" Sensor, Input Common	See pin H.	See pin H.	(f)	Ground potential	
		L	Measurement, Start Tank Gas Temperature, "B" Sensor, Output Common	See pin H.	See pin H.	(f)	Ground potential	
		M	Measurement, Helium Tank Gas Temperature, Sensor Output	-350° to +100° F	1,256 ±6	8.3×10^{-4} maximum	0.381 maximum	(d)
		N	Measurement, Oxidizer Pump Discharge Temperature, "B" Sensor, Input Common	See pin S.	See pin S.	(f)	Ground potential	

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 2 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		O	Measurement, Oxidizer Pump Discharge Temperature, "B" Sensor, Output Common	See pin S.	See pin S.	(f)	Ground potential	
		P	Measurement, Fuel Pump Discharge Temperature, "B" Sensor, Input Common	See pin V.	See pin V.	(f)	Ground potential	
		R	Measurement, Fuel Pump Discharge Temperature, "B" Sensor, Output Common	See pin V.	See pin V.	(b)	Ground potential	
		S	Measurement, Oxidizer Pump Discharge Temperature, "B" Sensor, Sensor Output	-300° to -250° F	1,256 ±6	5.8×10^{-4} maximum	0.214 maximum	(d)
		T	Measurement, Helium Tank Gas Temperature, Input Common	See pin M.	See pin M.	(b)	Ground potential	
		U	Measurement, Helium Tank Gas Temperature, Output Common	See pin M.	See pin M.	(f)	Ground potential	
		V	Measurement, Fuel Pump Discharge Temperature, "B" Sensor, Sensor Output	-425° to -400° F	1,256 ±6	4.7×10^{-3} maximum	5.49×10^{-2} maximum	(a)
		W	Measurement, Oxidizer Pump Discharge Temperature, "A" Sensor, Input Common	See pin b.	See pin b.	(f)	Ground potential	

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 3 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		X	Measurement, Oxidizer Pump Discharge Temperature, "A" Sensor, Output Common	See pin b.	See pin b.	(f)	Ground potential	
		Y	Spare Pin	--	--	--	--	
		Z	Measurement, Fuel Pump Discharge Temperature, "A" Sensor, Input Common	See pin e.	See pin e.	(f)	Ground potential	
		a	Measurement, Fuel Pump Discharge Temperature, "A" Sensor, Output Common	See pin e.	See pin e.	(f)	Ground potential	
		b	Measurement, Oxidizer Pump Discharge Temperature, "A" Sensor, Sensor Output	-300° to -250° F	1,256 ±6	7.0×10^{-4} maximum	--	(d)
(19) (20)	(18)	c	Measurement, Fuel Turbine Inlet Temperature Input Common	See pin k.	See pin k.	(f)	Ground potential	
(18)	(19) (20)	c	Spare Wire	--	--	--	--	--
(19) (20)	(18)	d	Measurement, Fuel Turbine Inlet Temperature, Output Common	See pin k.	See pin k.	(f)	Ground potential	
(18)	(19) (20)	d	Spare Wire	--	--	--	--	--
		e	Measurement, Fuel Pump Discharge Temperature, "A" Sensor, Sensor Output	-425° to -400° F	1,256 ±6	4.7×10^{-3} maximum	--	(d)

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 4 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(19) (22)	(18) (21)	f	Measurement, Oxidizer Turbine Outlet Temperature, Input Common	See pin m.	See pin m.	(f)	Ground potential	
(18) (21)	(19) (22)	f	Spare Wire	--	--	--	--	--
(19) (22)	(18) (21)	g	Measurement, Oxidizer Turbine Outlet Temperature, Output Common	See pin m.	See pin m.	(f)	Ground potential	
(18) (21)	(19) (22)	g	Spare Wire	--	--	--	--	--
(19) (20)	(18)	h	Measurement, Oxidizer Turbine Inlet Temperature, Input Common	See pin r.	See pin r.	(f)	Ground potential	--
(18)	(19) (20)	h	Spare Wire	--	--	--	--	--
(19) (20)	(18)	j	Measurement, Oxidizer Turbine Inlet Temperature, Output Common	See pin r.	See pin r.	(f)	Ground potential	
(18)	(19) (20)	j	Spare Wire	--	--	--	--	--
(19) (20)	(18)	k	Measurement, Fuel Turbine Inlet Temperature, Sensor Output	0° to 1,800° F	50 ±2	1.5×10^{-3} maximum	--	(d)
(18)	(19) (20)	k	Spare Wire	--	--	--	--	--
(19) (22)	(18) (21)	m	Measurement, Oxidizer Turbine Outlet Temperature, Sensor Output	0° to 1,000° F	50 ±2	1.5×10^{-3} maximum	--	(d)
(18) (21)	(19) (22)	m	Spare Wire	--	--	--	--	--

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 5 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Code							
		n	Measurement, Thrust Chamber Jacket Temperature No. 1, Input Common	See pin u.	See pin u.	(f)	Ground potential	
		p	Measurement, Thrust Chamber Jacket Temperature No. 1, Output Common	See pin u.	See pin u.	(f)	Ground potential	
(19) (20)	(18)	r	Measurement, Oxidizer Turbine Inlet Temperature, Sensor Output	0° to 1,200°F	50 ±2	1.5×10^{-3} maximum	--	(d)
(18)	(19) (20)	r	Spare Wire	--	--	--	--	--
		s	Measurement, Thrust Chamber Jacket Temperature No. 2, Sensor Output	-425° to +100°F	1,256 ±6	4.7×10^{-3} maximum	--	(d)
		t	Measurement, Fuel Injection Temperature, Sensor Output	-425° to -100°F	1,256 ±6	4.7×10^{-3} maximum	--	(d)
		u	Measurement, Thrust Chamber Jacket Temperature No. 1, Sensor Output	-425° to +100°F	1,256 ±6	4.7×10^{-3} maximum	--	--
		v	Measurement, Thrust Chamber Jacket Temperature No. 2, Input Common	See pin s.	See pins s.	(f)	Ground potential	
		w	Measurement, Fuel Injection Temperature, Input Common	See pin t.	See pin t.	(f)	Ground potential	
		x	Measurement, Thrust Chamber Jacket Temperature No. 2, Output Common	See pin s.	See pin s.	(f)	Ground potential	

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 6 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		y	Measurement, Fuel Injection Temperature, Output Common	See pin t.	See pin t.	(f)	Ground potential	
		z	Shield Return	--	--	Electrostatic shielding current	Ground potential	

Figure 11-4. Flight Instrumentation Interface Connector P108 (Sheet 7 of 7)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts AC	Remarks/Notes
Add	Delete							
		A	Command, Fuel Pump Tachometer Checkout Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 5,850 ±5 cps referenced to pin B	
		B	Command, Fuel Pump Tachometer Checkout Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 5,850 ±5 cps referenced to pin A	
		C	Measurement, Fuel Pump Tachometer Primary Signal Output	5,000-30,000 rpm	--	5×10^{-3} at 5 volts peak with 1,000-ohm load	1-8 peak at rated speed referenced to pin D	1/5 x rpm is frequency output in cps; (g)
		D	Measurement, Fuel Pump Tachometer, Primary Signal Output	5,000-30,000 rpm	--	5×10^{-3} at 5 volts peak with 1,000-ohm load	1-8 peak at rated speed referenced to pin C	1/5 x rpm is frequency output in cps; (g)
		E	Command, Oxidizer Pump Tachometer Checkout Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 1,920 ±2 cps referenced to pin F	

Figure 11-5. Flight Instrumentation Interface Connector P109 (Sheet 1 of 3)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts AC	Remarks/Notes
Add	Delete							
		F	Command, Oxidizer Pump Tachometer Checkout Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 1,920 ±2 cps referenced to pin E	
		G	Measurement, Oxidizer Pump Tachometer, Primary Signal Output	1,000-12,000 rpm	--	5 x 10^{-3} at 5 volts peak with 1,000-ohm load	1-8 peak at rated speed referenced to pin H	1/5 x rpm is frequency output in cps; (g)
		H	Measurement, Oxidizer Pump Tachometer, Primary Signal Output	1,000-12,000 rpm	--	5 x 10^{-3} at 5 volts peak with 1,000-ohm load	1-8 peak at rated speed referenced to pin G	1/5 x rpm is frequency output in cps; (g)
		J	Command, Fuel Flowmeter Checkout, Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200 ±0.2 cps referenced to pin K	
		K	Command, Fuel Flowmeter Checkout, Secondary Voltage	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200 ±0.2 cps referenced to pin J	
		L	Spare Pin	--	--	--	--	
		M	Spare Pin	--	--	--	--	
		N	Measurement, Fuel Flowmeter, Primary Signal Output	1,000-10,000 gpm	--	1 x 10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin P	1.8 pips per gallon nominal; (h) maximum current 6 x 10^{-3} amperes (i)
		P	Measurement, Fuel Flowmeter, Primary Signal Output	1,000-10,000 gpm	--	1 x 10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin N	1.8 pips per gallon nominal; (h) maximum current 6 x 10^{-3} amperes (i)
		R	Command, Oxidizer Flowmeter Checkout, Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200 ±0.2 cps referenced to pin S	

Figure 11-5. Flight Instrumentation Interface Connector P109 (Sheet 2 of 3)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts AC	Remarks/Notes
Add	Delete							
		S	Command, Main Oxidizer Flowmeter Checkout, Secondary Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200 ±0.2 cps referenced to pin R	
		T	Measurement, Oxidizer Flowmeter, Primary Signal Output	300-4,000 gpm	--	1×10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin U	5.5 pips per gallon nominal: (h) maximum current 6×10^{-3} amperes (m)
		U	Measurement, Oxidizer Flowmeter, Primary Signal Output	300-4,000 gpm	--	1×10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin T	5.5 pips per gallon nominal; (h) maximum current 6×10^{-3} amperes (m)
		V	Shield Return	--	--	Electrostatic shielding current	Ground potential	

Figure 11-5. Flight Instrumentation Interface Connector P109 (Sheet 3 of 3)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts AC	Remarks/Notes
Add	Delete							
		A	Ground Measurement, Fuel Flowmeter Signal Output	1,000-10,000 gpm	--	1.0×10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin B	1.8 pips per gallon nominal; (h)
		B	Ground Measurement, Fuel Flowmeter Signal Output	1,000-10,000 gpm	--	1.0×10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin A	1.8 pips per gallon nominal; (h)
		C	Ground Command, Fuel Flowmeter Checkout, Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200 ±0.2 cps referenced to pin D	
		D	Ground Command, Fuel Flowmeter Checkout, Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200 ±0.2 cps referenced to pin C	

Figure 11-6. Flight Instrumentation Interface Connector J110A

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts AC	Remarks/Notes
Add	Delete							
		A	Ground Measurement, Oxidizer Flowmeter Signal Output	300-4,000 gpm	--	1.0×10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin B	5.5 pips per gallon nominal; (h)
		B	Ground Measurement, Oxidizer Flowmeter Signal Output	300-4,000 gpm	--	1.0×10^{-3} at 3 volts peak with 3,000-ohm load	1-5 peak at rated flow referenced to pin A	5.5 pips per gallon nominal; (h)
		C	Ground Command, Oxidizer Flowmeter Checkout, Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200.0 ±0.2 cps referenced to pin D	
		D	Ground Command, Oxidizer Flowmeter Checkout, Voltage Input	--	--	0.02 maximum at 10 volts peak	9-11 peak at 200.0 ±0.02 cps referenced to pin C	

Figure 11-7. Flight Instrumentation Interface Connector J111A

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		A	Supply, Auxiliary Instrumentation Package, 28 vdc	--	--	1.44 maximum	24-32	Bussed to connector P154, pin U.
		B	Supply, Auxiliary Instrumentation Package, 28 vdc Return	--	--	2.32 maximum	Ground potential	Bussed to connector P154, pin c.
		C	Spare Wire	--	--	--	--	Bussed to connector P154, pin N.
		D	Supply, Auxiliary Instrumentation Package, 5 vdc Return	--	--	0.1 maximum	Ground potential	Bussed to connector P154, pin T.
	(6)	E	Prelaunch Heater Power	--	--	--	--	Not used
(6)		E	Spare Wire	--	--	--	--	

Figure 11-8. Flight Instrumentation Interface Connector P153 (Sheet 1 of 2)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
	(6)	F	Prelaunch Heater Return	--	--	--	--	Not used
(6)		F	Spare Wire	--	--	--	--	
	(6)	G	Flight Heater Power	--	--	--	--	Not used
(6)		G	Spare Wire	--	--	--	--	
	(6)	H	Flight Heater Return	--	--	--	--	Not used
(6)		H	Spare Wire	--	--	--	--	
		J	Spare Wire	--	--	--	--	
		K	Spare Wire	--	--	--	--	
		L	Spare Pin	--	--	--	--	
		M	Spare Pin	--	--	--	--	
		N	Spare Pin	--	--	--	--	
		P	Spare Pin	--	--	--	--	

Figure 11-8. Flight Instrumentation Interface Connector P153 (Sheet 2 of 2)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		A	Spare Wire	--	--	--	--	
		B	Spare Wire	--	--	--	--	
		C	Command, PO5 Dummy Pressure Transducer 80-Percent Calibration and Checkout Voltage Input	--	--	--	--	
		D	Spare Wire	--	--	--	--	
		E	Spare Wire	--	--	--	--	
		F	Spare Wire	--	--	--	--	
		G	Spare Wire	--	--	--	--	

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 1 of 8)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		H	Command, P195 Dummy Transducer, 20-Percent Calibration, Voltage Input	--	--	--	--	Dummy
		J	Measurement, P195 Dummy Transducer, Signal Output	Dummy	--	--	--	Dummy
		K	Command, P196 Dummy Transducer, 80-Percent Calibration, Voltage Input	--	--	--	--	Dummy
		L	Measurement, P196 Dummy Transducer, Signal Output	Dummy	--	--	--	Dummy
		M	Measurement, P197 Dummy Transducer, Signal Output	Dummy	--	--	--	Dummy
		N	Spare Wire	--	--	--	--	Bussed to connector P153, pin C.
	(23)	O	Command, PU Valve Inlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin V; (e)
	(23)	O	Command, MRCV Inlet Pressure 20-Percent Calibration	--	--	0.048 maximum	24-32	(a) pin V; (e)
	(23)	P	Command, PU Valve Inlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin V; (e)
	(23)	P	Command, MRCV Inlet Pressure 80-Percent Calibration	--	--	0.048 maximum	24-32	(b) pin V; (e)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 2 of 8)

Code								
Add	Delete	Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
		Q	Command, P196 Dummy Transducer, 20-Percent Calibration, Voltage Input	--	--	--	--	Dummy
		R	Command, P197 Dummy Transducer, 20-Percent Calibration, Voltage Input	--	--	--	--	Dummy
		S	Command, P197 Dummy Transducer, 80-Percent Calibration, Voltage Input	--	--	--	--	Dummy
		T	Supply, Auxiliary Instrumentation Package, 5 vdc Power Return Redundant	--	--	0.1 maximum	Ground potential	Bussed to connector P153, pin D.
		U	Supply, Auxiliary Instrumentation Package, 28 vdc Power (Redundant)	--	--	1.44 maximum	24-32	Bussed to connector P153, pin A.
	(4)	V	Measurement, PU Valve Inlet Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
(4)	(23)	V	Measurement, PU Valve Inlet Pressure, Signal Output	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
	(23)	V	Measurement, MRCV Inlet Pressure	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
	(23)	W	Measurement, PU Valve Outlet Pressure, Signal Output	0-500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
	(23)	W	Measurement, MRCV Outlet Pressure	0-500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 3 of 8)

Code								
Add	Delete	Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
	(23)	X	Command, PU Valve Outlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin W; (e)
	(23)	X	Command, MRCV Outlet Pressure 20-Percent Calibration	--	--	0.048 maximum	24-32	(a) pin W; (e)
	(23)	Y	Command, PU Valve Outlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin W; (e)
	(23)	Y	Command, MRCV Outlet Pressure, 80-Percent Calibration	--	--	0.048 maximum	24-32	(b) pin W; (e)
		Z	Command, Gas Generator Oxidizer Injection Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin b; (e)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 3A of 8)

Code								
Add	Delete	Pin	Functional Description	Range	R_0 (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
		a	Command, Gas Generator Oxidizer Injection Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin b; (e)
		b	Spare Wire	--	--	--	--	
		c	Supply, Auxiliary Instrumentation Package, 28 vdc Power Return (Redundant)	--	--	2.32 maximum	Ground potential	Bussed to connector P153, pin B.
	(17)	d	Command, Heat Exchanger Oxidizer Inlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin m; (e)
(17)		d	Spare Wire	--	--	--	--	
	(17)	e	Command, Heat Exchanger Oxidizer Inlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin m; (e)
(17)		_	Spare Wire	--	--	--	--	
	(5) (9)	f	Command, HF_2 Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin n; (e)
(5)	(9)	f	Command, HF_2 Pressure, 20-Percent Calibration, Voltage Input	--	--	--	--	Dummy
(9)		f	Command, Helium Tank Pressure, 20-Percent Calibration, (Redundant) Voltage Input	--	--	0.048 maximum	24-32	(a) pin n; (e)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 4 of 8)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
	(5) (9)	g	Command, HF_2 Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin n; (e)
(5)	(9)	g	Command, HF_2 Pressure Transducer, 80-Percent Calibration, Voltage Input	--	--	--	--	Dummy
(9)		g	Command, Helium Tank Pressure, 80-Percent Calibration, (Redundant) Voltage Input	--	--	0.048 maximum	24-32	(a) pin n; (e)
	(4)	h	Measurement, Gas Generator Oxidizer Injection Pressure, Signal Output	0-1,000 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
(4)		h	Measurement, Gas Generator Oxidizer Injection Pressure, Signal Output	0-1,500 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
		j	Command, Gas Generator Fuel Injection Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin s; (e)
		k	Command, Gas Generator Fuel Injection Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin s; (e)
	(4)(17)	m	Measurement, Heat Exchanger Oxidizer Inlet Pressure, Signal Output	0-1,000 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
(4)		m	Measurement, Heat Exchanger Oxidizer Inlet Pressure, Signal Output	0-1,500 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 5 of 8)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(17)		m	Spare Wire	--	--	--	--	
	(5) (9)	n	Measurement, HF_2 Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(e)
(5)	(9)	n	Measurement, HF_2 Pressure, Signal Output	Dummy	--	--	--	Dummy
(9) (12)		n	Measurement, Helium Tank Pressure, (Redundant) Signal Output	0-3,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(e)
(9) (13)		n	Measurement, Helium Tank Pressure, (Redundant) Signal Output	0-5,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(e)
		p	Measurement, Auxiliary Instrumentation Package Temperature, Input Common	See pin r.	See pin r.	(f)	Ground potential	
		q	Measurement, Auxiliary Instrumentation Package Temperature, Output Common	See pin r.	See pin r.	(f)	Ground potential	
		r	Measurement, Auxiliary Instrumentation Package Temperature, Sensor Output	-300° to +200° F	200 Ω	1.5 x 10^{-3} maximum	--	(d)
		s	Measurement, Gas Generator Fuel Injection Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(e)
	(9)	t	Command, Oxidizer Pump Bearing Coolant Pressure, 20-Percent Calibration, Voltage Input	--	--	0.04 maximum	24-32	(a) pin y; (e)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 6 of 8)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(9)		t	Command, Engine Start Tank Pressure, 20-Percent Calibration, (Redundant) Voltage Input	--	--	0.048 maximum	24-32	(b) pin y; (e)
	(9)	u	Command, Oxidizer Pump Bearing Coolant Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin y; (e)
(9)		u	Command, Engine Start Tank Pressure, 80-Percent Calibration, (Redundant) Voltage Input	--	--	0.048 maximum	24-32	(b) pin y; (e)
		v	Measurement, Oxidizer Pump Primary Seal Cavity Pressure Transducer Signal Output	0-50 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
		w	Command, Oxidizer Pump Primary Seal Cavity Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin y; (e)
		x	Command, Oxidizer Pump Primary Seal Cavity Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin y; (e)
	(9)	y	Measurement, Oxidizer Pump Bearing Coolant Pressure, Signal Output	0-500 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 7 of 8)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(9) (14)		y	Measurement, Engine Start Tank Pressure (Redundant), Signal Output	0-1,500 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
(9) (15)		y	Measurement, Engine Start Tank Pressure (Redundant), Signal Output	0-3,500 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
		z	Shield Return	--	--	Electrostatic shielding current	Ground potential	

Figure 11-9. Flight Instrumentation Interface Connector P154 (Sheet 8 of 8)

Code		Pin	Functional Description	Range	R_c (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		A	Spare Wire	--	--	--	--	
		B	Spare Wire	--	--	--	--	
		C	Spare Wire	--	--	--	--	
		D	Spare Wire	--	--	--	--	
		E	Measurement, Oxidizer Turbine Inlet Pressure, Signal Output	0-200 psia	--	$(5.0 \pm 0.1) \times 10^{-5}$ at 5 vdc	0-5	(c)
		F	Command, Oxidizer Turbine Inlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin F; (e)
		G	Command, Oxidizer Turbine Inlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin F; (e)

Figure 11-10. Flight Instrumentation Interface Connector P155 (Sheet 1 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
	(4)	H	Measurement, Main Fuel Injection Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
(4)		H	Measurement, Main Fuel Injection Pressure, Signal Output	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		J	Spare Wire	--	--	--	--	
		K	Measurement, Oxidizer Turbine Outlet Pressure, Signal Output	0-100 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		L	Command, Oxidizer Turbine Outlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin K; (e)
		M	Command, Oxidizer Turbine Outlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin K; (e)
		N	Command, Main Fuel Injection Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin H; (e)
		P	Command, Main Fuel Injection Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin H; (e)
	(4)	Q	Measurement, Main Oxidizer Injection Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)

Figure 11-10. Flight Instrumentation Interface Connector P155 (Sheet 2 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(4)		Q	Measurement, Main Oxidizer Injection Pressure, Signal Output	0-1,500 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		R	Measurement, Engine Regulator Outlet Pressure, Signal Output	0-750 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		S	Command, Engine Regulator Outlet Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin R; (e)
		T	Command, Engine Regulator Outlet Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin R; (e)
		U	Command, Main Oxidizer Injector Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin Q; (e)
		V	Command, Main Oxidizer Injector Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin Q; (e)
		W	Measurement, Fuel Pump Balance Piston Cavity Pressure, Signal Output	0-1,000 psia	--	(5.0 ±0.1) x 10^{-5} at 5 vdc	0-5	(c)
		X	Command, Fuel Pump Balance Piston Cavity Pressure, 20-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(a) pin W; (e)

Figure 11-10. Flight Instrumentation Interface Connector P155 (Sheet 3 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		Y	Command, Fuel Pump Balance Piston Cavity Pressure, 80-Percent Calibration, Voltage Input	--	--	0.048 maximum	24-32	(b) pin W; (e)
		Z	Spare Pin	--	--	--	--	

Figure 11-10. Flight Instrumentation Interface Connector P155 (Sheet 4 of 4)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		A	Spare Pin	--	--	--	--	
		B	Spare Pin	--	--	--	--	
		C	Spare Pin	--	--	--	--	
		D	Measurement, Oxidizer Bleed Valve Temperature, "B" Sensor, Input Common	See pin W.	See pin W.	(f)	Ground potential	
		E	Measurement, Oxidizer Bleed Valve Temperature, "B" Sensor, Output Common	See pin W.	See pin W.	(f)	Ground potential	
	(16)	F	Measurement, Heat Exchanger Oxidizer Outlet Temperature, "B" Sensor, Input Common	See pin X.	See pin X.	(f)	Ground potential	
(16)		F	Spare Wire	--	--	--	--	
	(16)	G	Measurement, Heat Exchanger Oxidizer Outlet Temperature, "B" Sensor, Output Common	See pin X.	See pin X.	(f)	Ground potential	
(16)		G	Spare Wire	--	--	--	--	

Figure 11-11. Flight Instrumentation Interface Connector P156 (Sheet 1 of 6)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
	(16)	H	Measurement, Heat Exchanger Oxidizer Outlet Temperature, "A" Sensor Input Common	See pin Y.	See pin Y.	(f)	Ground potential	
(16)		H	Spare Wire	--	--	--	--	
	(16)	J	Measurement, Heat Exchanger Oxidizer Outlet Temperature, "A" Sensor, Output Common	See pin Y.	See pin Y.	(f)	Ground potential	
(16)		J	Spare Wire	--	--	--	--	
		K	Measurement, Fuel Bleed Valve Temperature, "A" Sensor, Input Common	See pin Z.	See pin Z.	(f)	Ground potential	
		L	Measurement, Fuel Bleed Valve Temperature, "A" Sensor, Output Common	See pin Z.	See pin Z.	(f)	Ground potential	
		M	Measurement, Fuel Bleed Valve Temperature, "B" Sensor, Sensor Output	-425° to -325°F	1,256 ±6	4.7×10^{-3} maximum	9.1×10^{-2} maximum	(d)
[illegible] (3)		N	Measurement, Fuel Pump Bearing Coolant Temperature, Input Common	See pin <u>c</u>.	See pin <u>c</u>.	(f)	Ground potential	
(3)	(2)(3)	N	Spare Wire	--	--	--	--	
(2)		N	Measurement, Thrust Chamber Skin Temperature No. 2, Input Common	See pin <u>c</u>.	See pin <u>c</u>.	(f)	Ground potential	

Figure 11-13. Flight Instrumentation Interface Connector P156 (Sheet 2 of 6)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(8)		N	Measurement, Main Oxidizer Valve Housing Temperature, Input Common	See pin c.	See pin c.	(f)	Ground potential	
	(2)(3) (8)	P	Measurement, Fuel Pump Bearing Coolant Temperature, Input Common	See pin c.	See pin c.	(f)	Ground potential	
(3)	(2)(8)	P	Spare Wire	--	--	--	--	
(2)		P	Measurement, Thrust Chamber Skin Temperature No. 2, Output Common	See pin c.	See pin c.	(f)	Ground potential	
(8)		P	Measurement, Main Oxidizer Valve Housing Temperature, Output Common	See pin c.	See pin c	(f)	Ground potential	
	(11)	Q	Spare Wire	--	--	--	--	
(11)		Q	Return, Start Tank Emergency Vent	--	--	3.0 maximum	Ground potential	
		R	Spare Wire	--	--	--	--	
	(11)	S	Spare Wire	--	--	--	--	
(11)		S	Command Start Tank Emergency Vent	--	--	3.0 maximum	24-31	(k)
		T	Spare Wire	--	--	--	--	
		U	Spare Wire	--	--	--	--	
	(2)(8)	V	Measurement, Oxidizer Bleed Valve Temperature, "A" Sensor Output	-300° to -250°F	1,256 ±6	7.0×10^{-4} maximum	--	(o)

Figure 11-11. Flight Instrumentation Interface Connector P156 (Sheet 3 of 6)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
(2)		V	Measurement, Thrust Chamber Skin Temperature No. 1, Sensor Output	-425° to +100° F	1,256 ±6	4.7×10^{-3} maximum	--	(d)
(8)		V	Measurement, Main Oxidizer Valve Closing Control Line Temperature, Sensor Output	-300° to +100° F	100 ±2	2.1×10^{-3} maximum	--	(d)
		W	Measurement, Oxidizer Bleed Valve Temperature, "B" Sensor, Sensor Output	-300° to -250° F	1,256 ±6	7.0×10^{-4} maximum	--	(d)
	(16)	X	Measurement, Heat Exchanger Oxidizer Outlet Temperature, "B" Sensor, Sensor Output	-200° to +500° F	425 ±2	9.0×10^{-4} maximum	0.292 maximum	(d)
(16)		X	Spare Wire	--	--	--	--	
	(16)	Y	Measurement, Heat Exchanger Oxidizer Outlet Temperature, "A" Sensor, Sensor Output	-200° to +500° F	425 ±2	9.0×10^{-4} maximum	--	(d)
(16)		Y	Spare Wire	--	--	--	--	
		Z	Measurement, Fuel Bleed Valve Temperature, "A" Sensor, Sensor Output	-425° to -375° F	1,256 ±6	4.7×10^{-3} maximum	--	(d)
		$\underline{a}$	Measurement, Fuel Bleed Valve Temperature, "B" Sensor, Input Common	See pin M.	See pin M.	(f)	Ground potential	

Figure 11-11. Flight Instrumentation Interface Connector P156 (Sheet 4 of 6)

Code		Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
Add	Delete							
		b	Measurement, Fuel Bleed Valve Temperature, "B" Sensor, Output Common	See pin M.	See pin M.	(f)	Ground potential	
	(2)(3) (8)	c	Measurement, Fuel Pump Bearing Temperature, Sensor Output	-425° to -325°F	1,256 ±6	4.7×10^{-3} maximum	--	(d)
(3)	(2)(8)	c	Spare Wire	--	--	--	--	
(2)		c	Measurement, Thrust Chamber Skin Temperature No. 2, Sensor Output	-425° to +100°F	1,256 ±6	4.7×10^{-3} maximum	--	(a)
(8)		c	Measurement, Main Oxidizer Valve Housing Temperature, Sensor Output	-300° to +100°F	100 ±2	2.1×10^{-3} maximum	--	(d)
	(2)	d	Spare Wire	--	--	--	--	
	(2)(8)	e	Measurement, Oxidizer Bleed Valve Temperature, "A" Sensor, Input Common	See pin V.	See pin V.	(f)	Ground potential	
(2)		e	Measurement, Thrust Chamber Skin Temperature No. 1, Input Common	See pin V.	See pin V.	(f)	Ground potential	
(8)		e	Measurement, Main Oxidizer Valve Closing Control Line Temperature, Input Common	See pin V.	See pin V.	(f)	Ground potential	
	(2)(8)	f	Measurement, Oxidizer Bleed Valve Temperature, "A" Sensor, Output Common	See pin V.	See pin V.	(f)	Ground potential	

Figure 11-11. Flight Instrumentation Interface Connector P155 (Sheet 5 of 6)

Code								
Add	Delete	Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
(2)		f	Measurement, Thrust Chamber Skin Temperature No. 1, Output Common	See pin V.	See pin V.	(f)	Ground potential	
(8)		f	Measurement, Main Oxidizer Valve Closing Control Line Temperature, Output Common	See pin V.	See pin V.	(f)	Ground potential	
		g	Measurement, Oxidizer Pump Bearing Coolant Temperature, Sensor Output	-300° to -250° F	1,256 ±6	7.0 x 10^{-4} maximum	--	(d)
		h	Measurement, Oxidizer Pump Bearing Coolant Temperature, Output Common	See pin g.	See pin g.	(f)	Ground potential	
		j	Measurement, Oxidizer Pump Bearing Coolant Temperature, Input Common	See pin g.	See pin g.	(f)	Ground potential	
		k	Spare Wire	--	--	--	--	
		m	Shield Return	--	--	Electrostatic shielding current	Ground potential	

Figure 11-11. Flight Instrumentation Interface Connector P156 (Sheet 6 of 6)

Code								
Add	Delete	Pin	Functional Description	Range	R_o (Ohms)	Current (Amperes)	Volts DC	Remarks/Notes
		A	Measurement, Gas Generator Over-Temperature Thermocouple, Alumel Output	0° to 1,800°F	--	--	NSB Circular 561, Table 17	Grounded junction
		B	Measurement, Gas Generator Over-Temperature Thermocouple, Chromel Output	0° to 1,800°F	--	--	NBS Circular 561, Table 17	Grounded junction

Figure 11-12. Flight Instrumentation Interface Connector J160

(a) Application of voltage on this pin produces an electrical simulation causing an output on the referenced pin that is equivalent to 18-22 percent of the full-scale pressure plus applied pressure. The power requirements for this circuit must not exceed 1.54 watts over the voltage range of 24-32 vdc.

(b) Application of voltage on this pin produces an electrical simulation causing an output on the referenced pin that is equivalent to 78-82 percent of the full-scale pressure plus applied pressure. The power requirements for this circuit must not exceed 1.54 watts over the voltage range of 24-32 vdc.

(c) (Deleted)

(d) The maximum current specified is that current that will minimize self-heating of the sensor at the lower end of the temperature range. The maximum voltage specified is that voltage that will minimize self-heating of the sensor at the upper end of the temperature range.

(e) During the "off" condition, the leakage into this pin must be less than 50 microamperes into a 15,000-ohm load.

(f) The current balance for the three wires of the temperature transducer should be such that the line resistance is not made a significant part of the measurement.

(g) 1,000-ohm load recommended.

(h) 3,000-ohm load recommended.

(i) Power required by the valve switches is dependent on stage circuitry.

(j) Voltage ratios must be used to determine potentiometer position

where $$\text{Voltage ratio} = \frac{\text{potentiometer output volts}}{\text{potentiometer input volts}}$$

Any voltage drop between the power supply and the engine interface must be accounted for in determining the potentiometer input volts.

(k) 32 vdc maximum at initial application for a period not to exceed 60 seconds; ripple voltage not to exceed 2.1 volts peak. The maximum voltage transient limits must be a 60-volt positive pulse with a time width of 10 microseconds and a repetition rate of 20 cps.

(l) On SII stage engines the output wave form at connector P-109, pins P and N, with pin N as reference must consist of a negative going pulse followed immediately by a positive going pulse, such that the peak of the negative pulse is connected to the peak of the positive pulse by an approximate straight line of positive slope. (See figure 11-17A.)

(m) On SII stage engines the output wave form at connector P-109, pins U and T, with pin T as reference must consist of a negative going pulse followed immediately by a positive going pulse, such that the peak of the negative pulse is connected to the peak of the positive pulse by an approximate straight line of positive slope. (See figure 11-17A.)

Figure 11-13. Notes for Instrumentation Interface Connectors

Code	Engine Effectivity		ECP	MD	Description of Change
	Production	Retrofit			
(1)	J-2140 and subsequent	--	J2-405	237	Deletes redundant instrumentation bosses (GG1).
(2)	--	J-2031, J-2042, and J-2071	J2-415	200	Adds thrust chamber skin temperature transducers (CS2 and CS2a).
(3)	J-2060 and subsequent	--	J2-421	172	Deletes fuel turbopump bearing temperature (PST1).
(4)	J-2060 and subsequent	--	J2-445	172	Increases range of pressure tranducers (CF2, CO3, GO5, HO1, PO3, and PO8.
(5)	J-2060 and subsequent	--	J2-451	172	Deletes hydrogen tapoff outlet pressure (HF2).
	J-2103 and subsequent			206	
(6)	J-2060 and subsequent	--	J2-468	172	Deletes heaters from instrumentation packages.
(7)	J-2104 and subsequent	--	J2-523	233	Deletes fuel turbopump interstage pressure transducer (PF6).
(8)	--	J-2028, J-2035, J-2038, J-2040, J-2041, and J-2049	J2-527	248	Adds MOV housing and MOV closing control line temperature sensors.
(9)		J-2026, J-2028, and J-2030	J2-594	268	Adds redundant helium and start tank pressure transducers.
		J-2031, J-2035, J-2040, J-2041, J-2042, J-2043, J-2044, J-2049, J-2057, and J-2058		269	
		J-2025		279	
		J-2060, J-2062, J-2066 through J-2070, J-2073, J-2075 through J-2077, and J-2079 through J-2137		262	

Figure 11-14. Engine Effectivity for Instrumentation Interface Connectors (Sheet 1 of 4)

	Engine Effectivity				
Code	Production	Retrofit	ECP	MD	Description of Change
(9) (cont)		J-2038, J-2045, J-2049, J-2050, J-2051, J-2053, J-2054, J-2055, and J-2059		296	
		J-2033, J-2036, J-2037, J-2039, J-2046, J-2048, J-2052, and J-2056		313	
		J-2071		314	
	J-2138 and subsequent			315	
(10)	--	J-2025, J-2033, J-2054, J-2095, and J-2103	J2-616	303 304	Provides for low-range thrust chamber pressure measurement.
(11)	--	J-2033, J-2045, J-2049, J-2051, J-2053, J-2055, J-2059, J-2071, and J-2073	J2-624	316	Adds start tank emergency vent valve.
		One engine incorporating ECP J2-547 (MD241)		317	
	J-2145 and subsequent	J-2066 through J-2070, J-2075 through J-2077, J-2080, J-2081, J-2091, J-2094, J-2101, J-2119, and J-2122		320	
		J-2045, J-2051, J-2053, J-2055, and J-2059		342	
		J-2045, J-2049, J-2051, J-2053, J-2055, J-2059, J-2066 through J-2070, J-2075 through J-2077, J-2080, J-2081, J-2091, J-2101, J-2119, and J-2122		351	

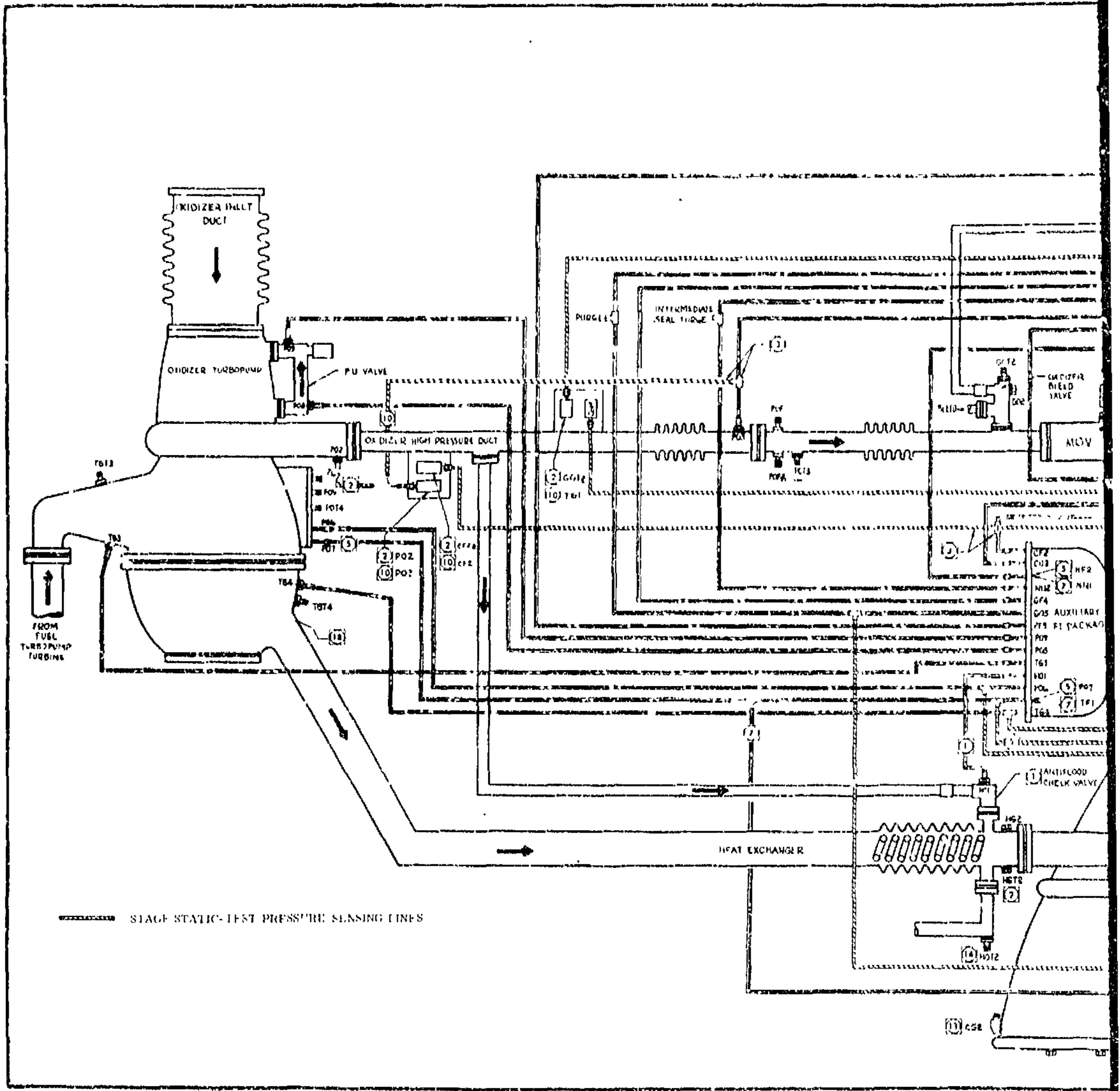
Figure 11-14. Engine Effectivity for Instrumentation Interface Connectors (Sheet 2 of 4)

Code	Engine Effectivity		ECP	MD	Description of Change
	Production	Retrofit			
(11) (cont)		J-2039-1, J-2046, J-2056, J-2062, J-2079, J-2082 through J-2090, J-2092, J-2093, J-2095 through J-2100, J-2102 through J-2118, J-2121, J-2123 through J-2130, and J-2132 through J-2144		320 and 351 (-70 kit)	
(12)	(See code 9.)	(See code 9.)	J2-594	268, 269, 279, 296, and 314	Installs 0-3,500 psia helium tank pressure transducer.
(13)	(See code 9.)	(See code 9.)	J2-594	282, 313, and 315	Installs 0-5,000 psia helium tank pressure transducer.
(14)	(See code 9.)	(See code 9.)	J2-594	268, 269, and 270	Installs 0-1,500 psia start tank pressure transducer.
(15)	(See code 9.)	(See code 9.)	J2-594	282, 296, 313, 314, and 315	Installs 0-3,500 psia start tank pressure transducer.
(16)	--	J-2025, J-2027, J-2031, J-2033, J-2042, J-2046, J-2048, J-2052, J-2054, J-2056, J-2062, J-2071, J-2073, J-2079, J-2083, J-2087, J-2091, J-2094, J-2095, J-2101, J-2013, J-2119, J-2122, J-2124, J-2134, J-2138, J-2142, J-2145, J-2148, J-2150, J-2152, J-2154, and J-2155	J2-320	100	Adds cover plate. (Removes transducer HOT2 from engines assigned to SIVB stage.)
(17)	--	J-2025, J-2027, J-2031, J-2033, J-2034, J-2042, J-2046, J-2048, J-2052, J-2054, and J-2056	J2-293	105	Adds helium pressurization line. (Deletes HO1.)

Figure 11-14. Engine Effectivity for Instrumentation Interface Connectors (Sheet 3 of 4)

Code	Engine Effectivity		ECP	MD	Description of Change
	Production	Retrofit			
(17) (cont)		J-2060, J-2062, J-2071, J-2073, J-2079, J-2083, J-2087, J-2091, J-2094, J-2095, J-2101, J-2103, J-2110, J-2122, J-2124, J-2134, J-2138, J-2142, J-2145, J-2148, J-2150, J-2152, J-2154, and J-2155	J2-428	194	Changes helium heat exchanger pressure requirements. (Effectivity the same as ECP J2-293)
(18)	J-2104 through J-2139	--	J2-588	263	Changes temperature transducers. (Replaces old-part-number transducers for TGT1, TGT3, and TGT4 with dummy transducers.)
(19)	--	J-2104 through J-2127, J-2133, J-2134, and J-2137		274	Changes temperature transducers. (Replaces dummy transducers with new-part-number transducers for TGT1, TGT3, and TGT4.)
(20)	J-2140 and subsequent	J-2128 through J-2130, J-2132, J-2135, J-2136, J-2138, and J-2139		355	Changes temperature transducers. (Replaces dummy transducers (retrofit) or installs (production) new-part-number transducers for TGT1 and TGT3; leaves dummy transducer installed for TGT4.)
(21)	--	J-2028, J-2084 through J-2086, J-2088 through J-2090, J-2092, J-2093, J-2096 through J-2100, J-2102, J-2104 through J-2118, J-2121, J-2123, and J-2125 through J-2127		355	Changes temperature transducers. (Replaces functional transducer for TGT4 with dummy transducer after MD274 change (code 19) has been accomplished.)
(22)	--	J-2140, J-2143, J-2146, and J-2152		274	Changes temperature transducers. (Replaces dummy transducer with new-part-number transducer for TGT4 after MD355 change (code 20) has been accomplished.)
(23)	--	J-2036-1, J-2039-1, J-2046 and subsequent	J2-689	366, 371	Incorporation of two position mixture ratio control valve.

Figure 11-14. Engine Effectivity for Instrumentation Interface Connectors (Sheet 4 of 4)


OXIDIZER INLET DUCT
OXIDIZER TURBOPUMP
PU VALVE
OXIDIZER HIGH PRESSURE DUCT
PO2
FOV
FOT4
PO6
POT
3
2 PO2
10 PO2
2 CF2A
10 CF2
10
TG13
FROM FUEL TURBOPUMP TURBINE
TG3
TG4
TGT4
18
PURGE
INTERMEDIATE SEAL PURGE
3
2 GG1E
10 TF1
3
PLF
POPA
TC13
GXT2
GX2
OXIDIZER BLEED VALVE
MOV
2
CF2
CO3
NN2
CF4
CO5
PF9
PO9
PO6
TG1
HO1
POL
TG3
5 HF2
7 NN1
AUXILIARY FT PACKAGE
5 PO7
7 TF1
1
1 ANTIFLOOD CHECK VALVE
HF1
HG2
HEAT EXCHANGER
HGT2
2
14 HGT2
7
13 CG2
STAGE STATIC-TEST PRESSURE SENSING LINES

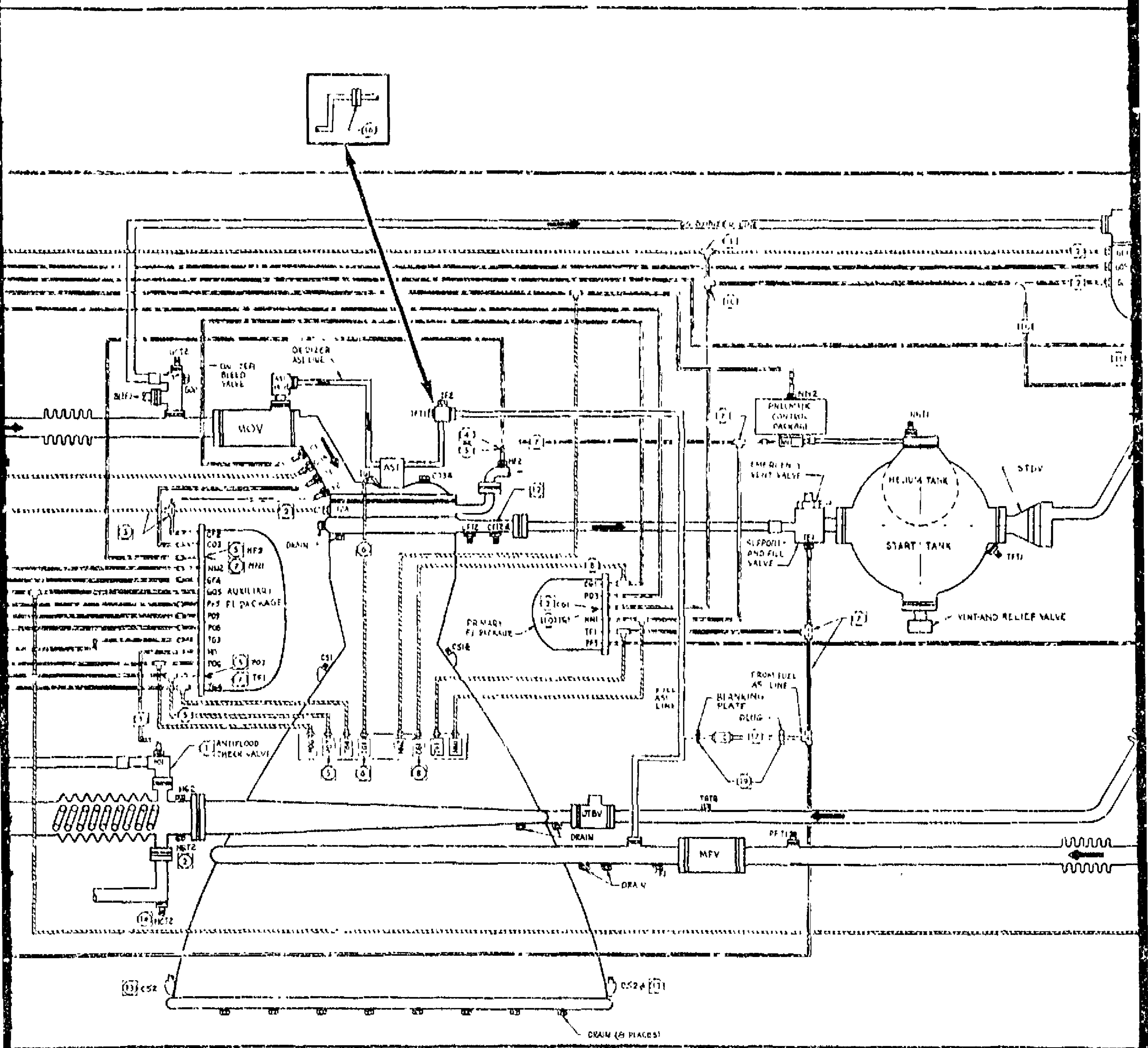


Figure 11-15. Engine Ins

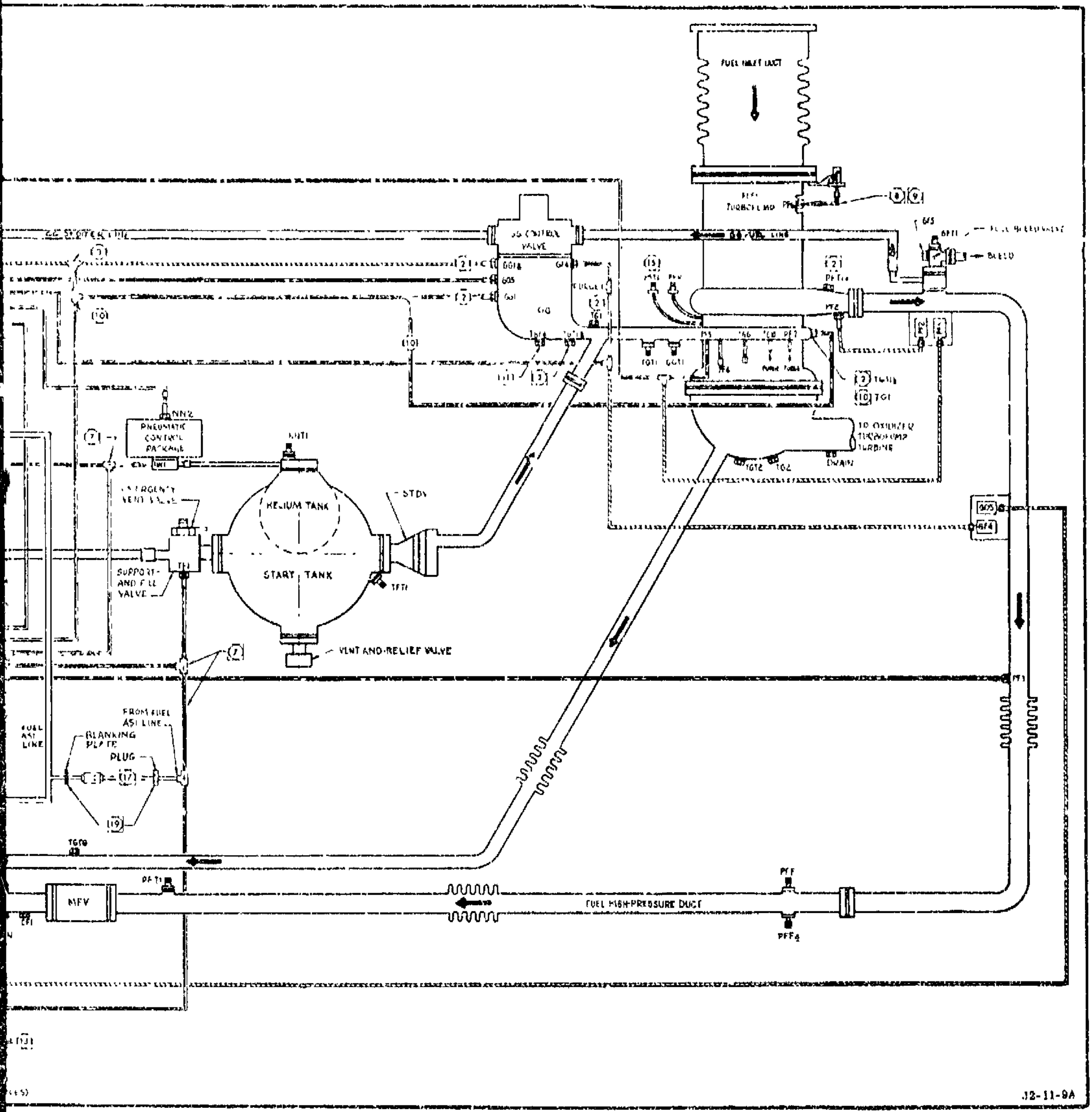


Figure 11-15. Engine Instrumentation Tap Location Schematic (Sheet 1 of 2)

① Removed on engines incorporating MD105 or MD194 change

② Removed on engines incorporating MD237 change

③ Two lines teed together on engines incorporating MD237 change

④ Removed on engines incorporating MD172 or MD200 change

⑤ Removed on engines incorporating MD269, MD282, MD296, MD313, or MD315 change

⑥ Removed on engines incorporating MD192 or MD246 change

⑦ Redundant instrumentation added on engines incorporating MD269, MD282, MD296, MD313, or MD315 change

⑧ Removed on engines incorporating MD304 change

⑨ Removed on engines incorporating MD233 change

⑩ Engines incorporating MD237 change

⑪ Removed on engines incorporating MD136 change

⑫ Removed on engines incorporating MD262 change

⑬ Engines incorporating MD200 change

⑭ Removed on engines incorporating MD100 change

⑮ Removed on engines incorporating MD172 change

⑯ Engines incorporating MD327, MD328, MD329, MD332, or MD334 change

⑰ Engines incorporating MD331 or MD344 change but not incorporating MD347 change

⑱ Engines not incorporating MD263 or MD355 change

⑲ Engines incorporating MD347 change

Figure 11-15. Engine Instrumentation Tap Location Schematic (Sheet 2 of 2)

Change Code		Parameter	Tap Code	Instrumentation System	Electrical Connector
Add	Delete				
		PRESSURE			
		Thrust chamber fuel inlet manifold	CF1	Acceptance test	-
		Main fuel injection	CF2	Auxiliary flight	J184
(a)		Main fuel injection	CF2 (teed)	Stage test	-
	(a)	Main fuel injection	CF2a	Stage test	-
		Thrust chamber	CG1	Primary flight	J137
	(b)	Thrust chamber	CG1 (teed)	Stage test	-
(b)		Thrust chamber	CG1 (teed)	Primary flight	J141
		Thrust chamber	CG1a	Stage and acceptance tests	-
		Main oxidizer injection	CO3	Auxiliary flight	J193
		Main oxidizer injection	CO3a	Acceptance test	-
		GG fuel injector and purge line	GF4	Auxiliary flight	J182
		GG fuel injector and purge line	GF4 (teed)	Stage test	-
	(a)	GG chamber	GG1	Primary flight	J138
	(a)	GG chamber	GG1a	Stage test	-
		GG oxidizer injector and purge line	GO5	Auxiliary flight	J181
		GG oxidizer injector and purge line	GO5 (teed)	Stage test	-
	(c)(d)	Hydrogen tapoff outlet	HF2	Auxiliary flight	J187
	(e)	Heat exchanger oxidizer inlet	HO1	Auxiliary flight	J188
	(f)	ASI chamber	IG1	Stage and acceptance tests	-
		Helium tank	NN1	Primary flight	J139
		Helium tank	NN1 (teed)	Stage test	-
(d)		Helium tank (redundant)	NN1 (teed)	Auxiliary flight	J187
		Helium regulator outlet	NN2	Auxiliary flight	J183
		Helium regulator outlet	NN2 (teed)	Stage test	-
		Fuel turbopump discharge	PF2	Stage and acceptance tests	-

(a) Engines incorporating MD237 change
(b) Engines incorporating MD303 or MD304 change
(c) Engines incorporating MD172 or MD206 change
(d) Engines incorporating MD209, MD282, MD296, MD313, MD314, or MD315 change
(e) Engines incorporating MD105 or MD194 change
(f) Engines incorporating MD192 or MD246 change

Figure 11-16. Engine Instrumentation List (Sheet 1 of 6)

Change Code		Parameter	Tap Code	Instrumentation System	Electrical Connector
Add	Delete				
		PRESSURE (cont)			
		Fuel turbopump discharge	PF3	Primary flight	J135
		Fuel turbopump balance piston cavity	PF4	Acceptance test	-
		Fuel turbopump balance piston cavity	PF5	Auxiliary flight	J194
		Fuel turbopump balance piston cavity	PF5 (teed)	Stage test	-
	(b)(g)	Fuel turbopump interstage	PF6	Auxiliary flight	J141
		Fuel turbopump primary seal	PF7	R&D test	-
	(a)	Oxidizer turbopump discharge	PO2	Stage and acceptance tests	-
		Oxidizer turbopump discharge	PO3	Primary flight	J136
(a)		Oxidizer turbopump discharge	PO3 (teed)	Stage and acceptance tests	-
		Oxidizer turbopump primary seal	PO6	Auxiliary flight	J189
		Oxidizer turbopump primary seal	PO6 (teed)	Stage test	-
	(d)	Oxidizer turbopump bearing coolant	PO7	Auxiliary flight	J190
	(d)	Oxidizer turbopump bearing coolant	PO7 (teed)	Stage test	-
		PU valve inlet	PO8	Auxiliary flight	J185
		PU valve outlet	PO9	Auxiliary flight	J191
		Start tank	TF1	Primary flight	J140
		Start tank	TF1 (teed)	Stage test	-
(d)		Start tank (redundant)	TF1 (teed)	Auxiliary flight	J190
	(a)	Fuel turbine inlet	TG1	Acceptance test	-
(a)(h)		Fuel turbine inlet	TG1	Primary flight	J138
(a)(h)		Fuel turbine inlet	TG1 (teed)	Stage test	-
	(i)	Fuel turbine inlet	TG1a	Acceptance test	-
		Fuel turbine exhaust	TG2	Acceptance test	-
		Oxidizer turbine inlet	TG3	Auxiliary flight	J192
		Oxidizer turbine exhaust	TG4	Auxiliary flight	J186
		Oxidizer turbine exhaust	TG4 (teed)	Stage test	-
	(a)(j)	OTBV inlet	TG8	Stage test	-
		Fuel turbopump turbine seal	TG10	R&D test	-

(a) Engines incorporating MD237 change
(b) Engines incorporating MD303 or MD304 change
(d) Engines incorporating MD269, MD282, MD296, MD313, MD314, or MD315 change
(g) Engines incorporating MD233 change
(h) Original TG1 tap is removed, and new TG1 tap is at former TGT1b tap location.
(i) Engines incorporating MD136 change
(j) Engines incorporating MD226 change

Figure 11-16. Engine Instrumentation List (Sheet 2 of 6)

Change Code		Parameter	Tap Code	Instrumentation System	Electrical Connector
Add	Delete				
		TEMPERATURE			
		Main fuel injection	CFT2	Primary flight and stage test	J131 (k)
	(l)	Main fuel injection	CFT2a	Primary flight and stage test	J22 -
		Thrust chamber jacket No. 1	CS1	Primary flight	J129
		Thrust chamber jacket No. 2	CS1a	Primary flight and stage test	J130 (k)
(m)		Thrust chamber skin No. 1	CS2	Primary flight	J159
(m)		Thrust chamber skin No. 2	CS2a	Auxiliary flight	J161
		Fuel bleed valve	GFT1	Primary flight and stage test	J158 (n)
		Fuel turbine inlet (GG overtemperature)	GGT1	Acceptance test	J160
	(m)(o)	Oxidizer bleed valve	GOT2	Primary flight and stage test	J159 (n)
(o)		MOV closing control line	-	Primary flight and stage test	J159
	(a)	Heat exchanger	HGT2	R&D and acceptance test	-
	(p)	Heat exchanger oxidizer outlet	HOT2	Auxiliary flight and stage test	J157 (n)
	(x)	ASI fuel injection	IFT1	Acceptance test	-
		Helium tank	NNT1	Primary flight	J122
		Fuel turbopump discharge	PFT1	Primary flight and stage test	J124 (n)
	(a)	Fuel turbopump discharge	PFT1a	R&D and acceptance test	-
		Oxidizer turbopump discharge	POT3	Primary flight and stage test	J125 (n)
		Oxidizer turbopump bearing coolant	POT4	Auxiliary flight and stage test	J162 (k)
	(m)(o) (q)	Fuel turbopump bearing	PST1	Auxiliary flight and stage test	J161 (k)
(o)		MOV housing	-	Auxiliary flight and stage test	J161
		Start tank	TFT1	Primary flight and stage test	J123 (n)

(a) Engines incorporating MD237 change
(k) Flight electrical harness is removed and drag-in harness connected to obtain static-test measurement.
(l) Engines incorporating MD262 change
(m) Engines incorporating MD200 change
(n) Dual-element transducer; stage-test electrical signal at vehicle patch-panel
(o) Engines incorporating MD248 change
(p) Engines incorporating MD100 change
(q) Engines incorporating MD172 change
(x) Engines incorporating MD327, MD328, MD329, MD332, or MD344 change

Figure 11-16. Engine Instrumentation List (Sheet 3 of 6)

Change Code		Parameter	Tap Code	Instrumentation System	Electrical Connector
Add	Delete				
		TEMPERATURE (cont)			
(s)	(r)	Fuel turbine inlet	TGT1	Primary flight	J126
	(a)	Fuel turbine inlet	TGT1a	Stage test	-
	(a)(h)	Fuel turbine inlet	TGT1b	Stage test	-
		Fuel turbine exhaust	TGT2	Stage and acceptance tests	-
(s)	(r)	Oxidizer turbine inlet	TGT3	Primary flight	J127
(z)	(y)	Oxidizer turbine outlet	TGT4	Primary flight	J128
	(a)	OTBV inlet	TGT6	Stage test	-
		Electrical control assembly		Primary flight	J2
		Electrical control assembly		Stage test	J2
		Primary FI package		Primary flight	J103
		Auxiliary FI package		Auxiliary flight	P151
		SPEED			
		Fuel turbopump	PFV	Primary flight and stage test	J112 (t)
		Oxidizer turbopump	POV	Primary flight and stage test	J113 (t)
		FLOWRATE			
		Engine main fuel	PFF	Primary flight	J110
		Engine main fuel	PFFa	Stage test	J110A
		Engine main oxidizer	POF	Primary flight	J111
		Engine main oxidizer	POFa	Stage test	J111A
		POSITION			
		MFV		Primary flight and stage test	J114 (u)
		MOV		Primary flight and stage test	J115 (u)
		GG control valve		Primary flight and stage test	J116 (u)
		Fuel bleed valve		Primary flight and stage test	J113 (u)
		Oxidizer bleed valve		Primary flight and stage test	J132
		OTBV		Primary flight and stage test	J117 (u)

(a) Engines incorporating MD237 change

(h) Original TG1 tap is removed, and new TG1 tap is at former TGT1b tap location.

(r) On engines incorporating MD263 change, transducer port is plugged.

(s) On engines incorporating MD274 or MD355 change, plug is replaced by new transducer.

(t) Secondary (calibration coil is used for stage measurement; electrical signal is at vehicle patch-panel.

(u) Stage-test applies to potentiometer trace.

(y) On engines incorporating MD263 or MD355 change, transducer port is plugged.

(z) On engines incorporating MD274 change, plug is replaced by new transducer.

Figure 11-16. Engine Instrumentation List (Sheet 4 of 6)

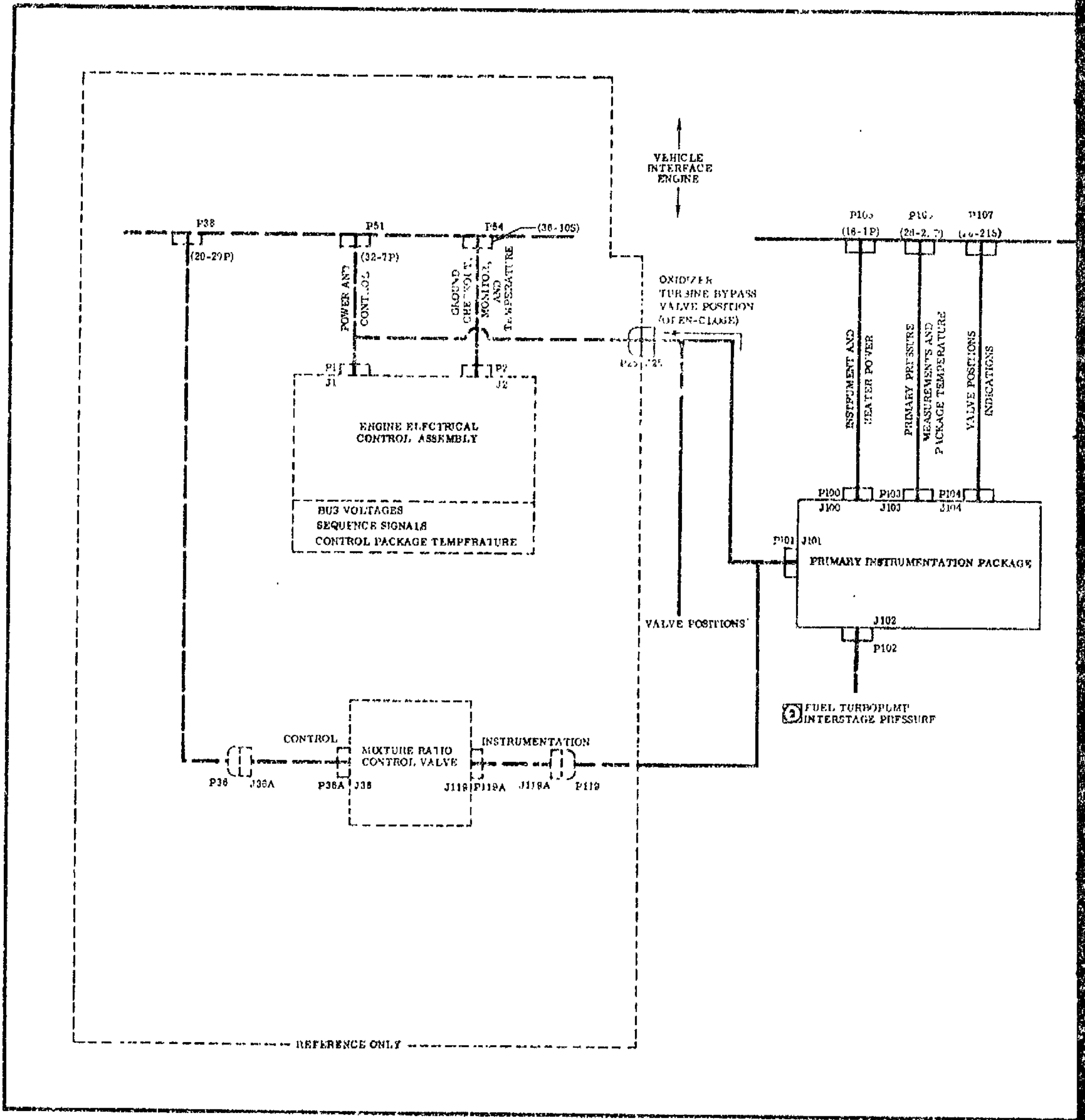
Change Code		Parameter	Tap Code	Instrumentation System	Electrical Connector
Add	Delete				
		POSITION (cont)			
		ASI valve		Primary flight	J120
		PU valve		Primary flight and stage test	J119
		STDV		Primary flight and stage test	J118
		Oxidizer dome compliance No. 1		Acceptance test	-
		Oxidizer dome compliance No. 2		Acceptance test	-
		Oxidizer dome compliance No. 3		Acceptance test	-
		Oxidizer dome compliance No. 4		Acceptance test	-
		VIBRATION			
		Thrust chamber injector dome No. 1		Stage and acceptance tests	
		Thrust chamber injector dome No. 2		Stage and acceptance tests	
		Thrust chamber injector dome No. 3		Stage and acceptance tests	
		Fuel turbopump inlet No. 1		Stage and acceptance tests	
		Fuel turbopump inlet No. 2		Stage test	
		Oxidizer turbopump inlet No. 1		Stage and acceptance tests	
		Oxidizer turbopump inlet No. 2		Stage test	
		VOLTAGE			
		Ignition bus		Primary flight and stage test	J2
		Control bus		Primary flight and stage test	J2
		RATE			
		GG spark No. 1		Stage and acceptance tests	J2
		GG spark No. 2		Stage and acceptance tests	J2
		ASI spark No. 1		Stage and acceptance tests	J2
		ASI spark No. 2		Stage and acceptance tests	J2

Figure 11-16. Engine Instrumentation List (Sheet 5 of 6)

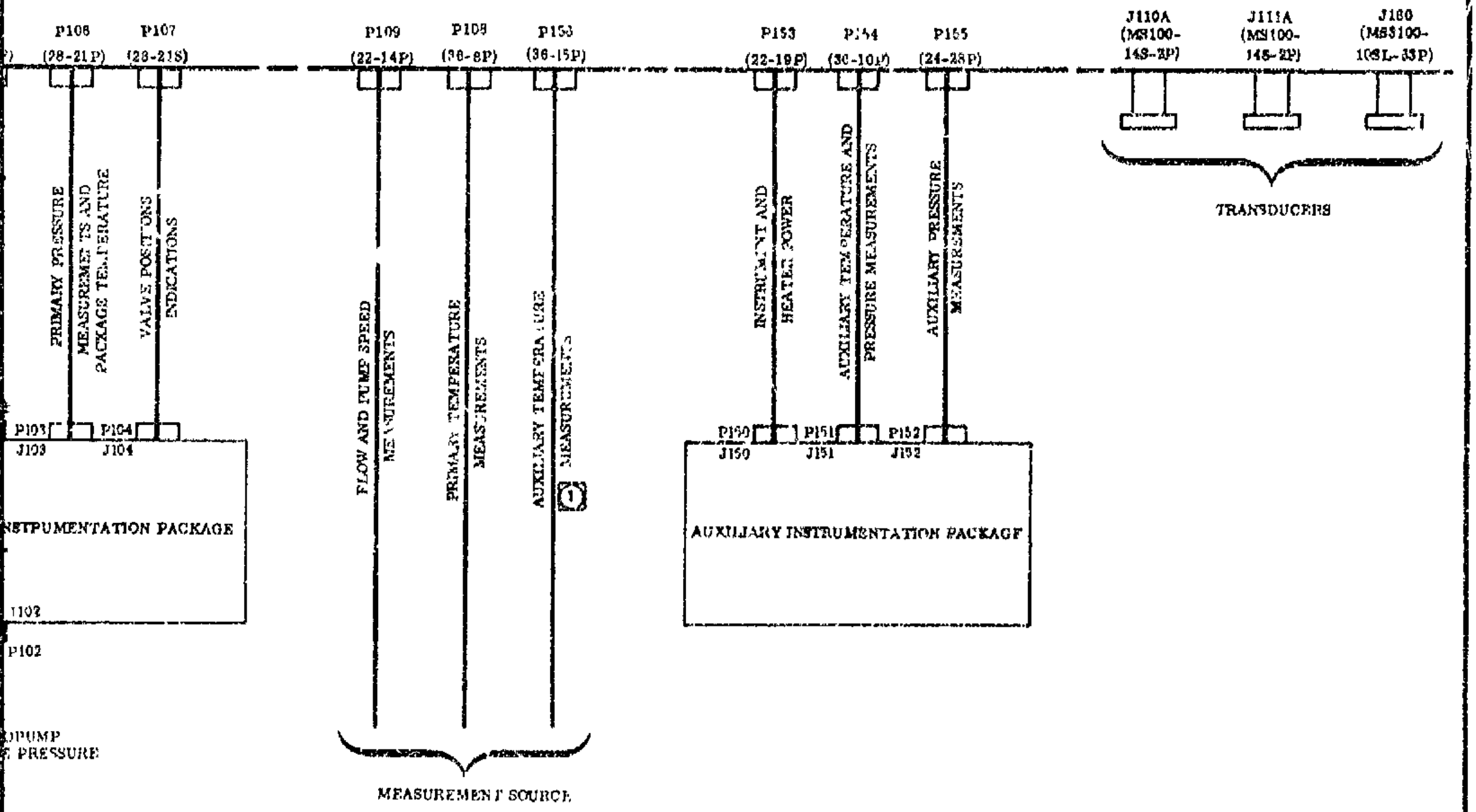
Change Code		Parameter	Tap Code	Instrumentation System	Electrical Connector
Add	Delete				
		ELECTRICAL SIGNALS			
		Engine ready		Primary flight and stage test	J1
		Helium control on		Primary flight and stage test	J2
		Ignition-phase control on		Primary flight and stage test	J2
		ASI spark on		Primary flight	J2
		GG spark on		Primary flight	J2
		Mainstage control on		Primary flight and stage test	J2
		Start tank discharge control on		Primary flight and stage test	J2
	(v)	Start tank pressurized		Primary flight and stage test	J2
(v)	(w)	Spare monitor-jumper installed			
	(v)	Start tank depressurized		Primary flight and stage test	J2
(v)	(w)	Spare monitor-jumper installed			
		Ignition complete		Primary flight and stage test	J2
		Mainstage OK No. 1 pressurized		Primary flight and stage test	J1
		Mainstage OK No. 2 pressurized		Primary flight and stage test	J1
		Mainstage OK No. 1 depressurized		Primary flight and stage test	J2
		Mainstage OK No. 2 depressurized		Primary flight and stage test	J2
	(w)	Fuel injection temperature OK (main fuel injection temperature)	CFT2a	Primary flight and stage test	J2
		Engine cutoff vehicle		Primary flight	J1
		Engine cutoff lock-in		Primary flight and stage test	J2

(v) Engines incorporating MD163, MD174, or MD202 change
(w) Engines incorporating MD204 change

Figure 11-16. Engine Instrumentation List (Sheet 6 of 6)


VEHICLE
INTERFACE
ENGINE
P38
(20-29P)
P51
(32-7P)
P54
(36-10S)
POWER AND CONTROL
GROUND CHECK VOLTS, MONITOR, AND TEMPERATURE
P1
J1
P2
J2
ENGINE ELECTRICAL CONTROL ASSEMBLY
BUS VOLTAGES
SEQUENCE SIGNALS
CONTROL PACKAGE TEMPERATURE
OXIDIZER TURBINE BYPASS VALVE POSITION (OPEN-CLOSE)
P25
J25
VALVE POSITIONS
P105
(16-1P)
P106
(28-2.7)
P107
(26-21S)
INSTRUMENT AND HEATER POWER
PRIMARY PRESSURE MEASUREMENTS AND PACKAGE TEMPERATURE
VALVE POSITIONS INDICATIONS
P100
J100
P103
J103
P104
J104
P101
J101
PRIMARY INSTRUMENTATION PACKAGE
J102
P102
FUEL TURBOPUMP INTERSTAGE PRESSURE
CONTROL
MIXTURE RATIO CONTROL VALVE
INSTRUMENTATION
P38
J38A
P38A
J38
J119
P119A
J119A
P119
REFERENCE ONLY

F



1 ON ENGINES INCORPORATING MD320 OR MD351 CHANGE, START TANK EMERGENCY VENT VALVE CONTROL SOLENOID IS CONNECTED THROUGH P155.

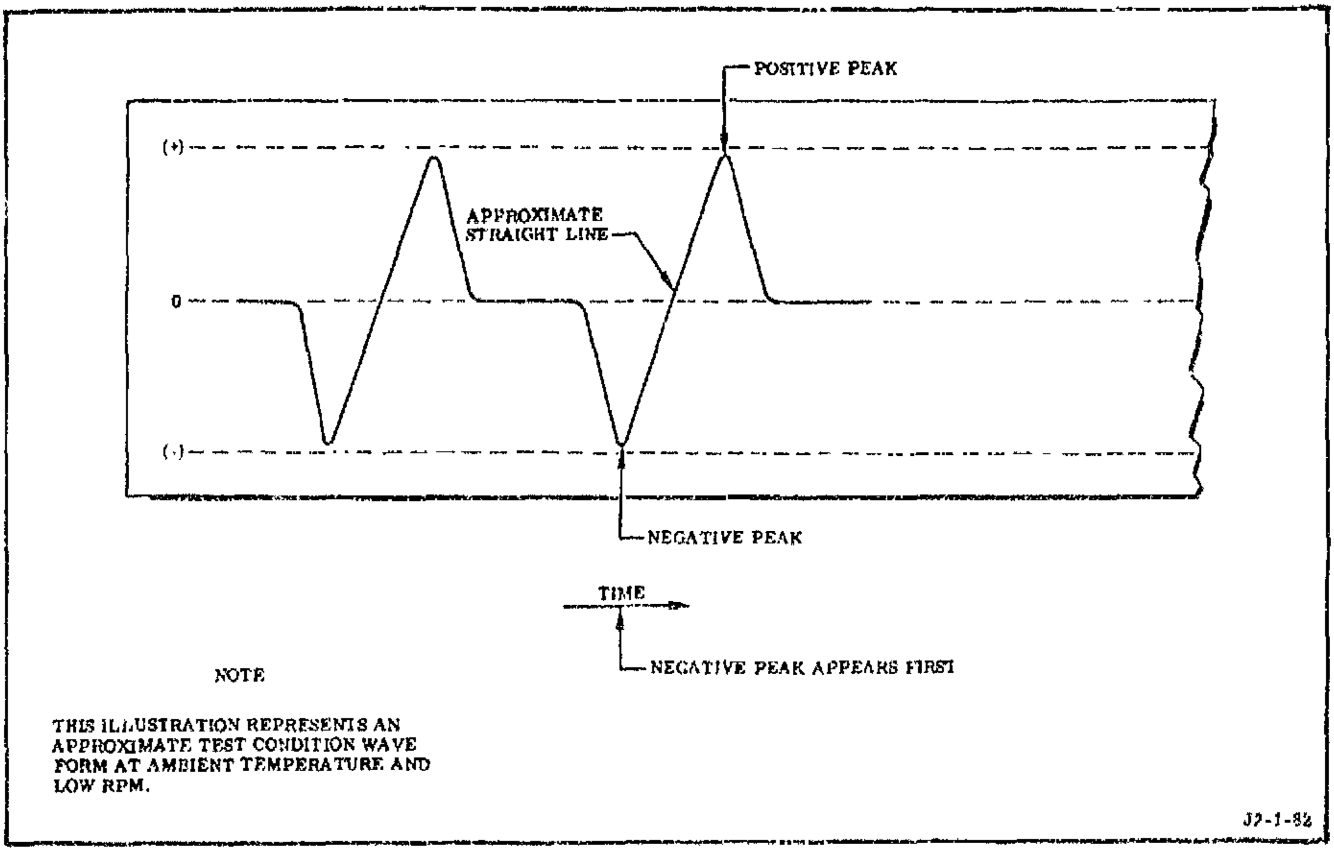
2 ENGINES NOT INCORPORATING MD223 CHANGE

NOTE

CONNECTOR SIZES SHOWN IN PARENTHESES

J2-1-14C

Figure 11-17. Engine-to-Vehicle Electrical and Instrumentation Interface Schematic



NOTE

THIS ILLUSTRATION REPRESENTS AN APPROXIMATE TEST CONDITION WAVE FORM AT AMBIENT TEMPERATURE AND LOW RPM.

Figure 11-17A. Fuel and Oxidizer Flowmeter Output Polarity (SII Stage)

11-5. DESIGN CRITERIA.

11-6. The basic design criteria are as follows:

NOTE

> Section VII contains detailed information on transducer types, data control, and processing.

a. The accuracy of each parameter at the output of the engine-supplied instrumentation system will be within ±2.0 percent, except on engines not incorporating MD172 change; the thrust chamber P_c will be within ±0.5 percent and the gas generator P_c will be within ±1.0 percent. The accuracy includes any error caused by calibration of the transducer. It will be a design objective to achieve accuracies equal with those required for an overall vehicle instrumentation within ±5 percent. The required measurement accuracies of all pressure parameters can be obtained only by compensating for long-term transducer drift by the methods described for pressure transducer data reduction in section VII. If compensation for transducer drift is not performed, errors in excess of ±10 percent are possible at the engine interface.

b. The transducers will not require physical calibration after installation on the engine. Provisions for applying an electrical signal to each measurement are incorporated for automatic checkout, except those parameters for which the vehicle contractor provides signal conditioning.

c. Protection is provided where transducers, tubing, or cable harnesses may possibly be damaged during assembly and checkout of the vehicle.

d. Each potentiometer-type transducer must have an excitation voltage of +5 vdc; transducers with integral electronics, +24 to +32 vdc.

e. Transducers with integral electronics provide a 0-5 vdc output into any specified load between 100,000 and 500,000 ohms. Signal conditioning of all other transducers is provided by the vehicle contractor.

f. Any measurements or signals required for engine control or sequencing must be a part of the engine control package.

g. Pin functions for potentiometers are shown in figure 11-18.

h. Pin functions for dc-dc type pressure transducers are as follows:

(1) Pin A: +28 volt positive excitation

(2) Pin B: +5 positive output voltage

(3) Pin C: -5 negative output voltage return

(4) Pin D: -28 negative excitation voltage return

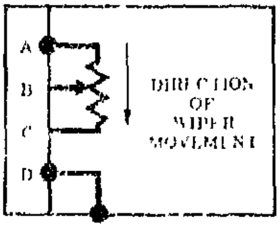
(5) Pin E: +28 volt, 20-percent calibration excitation

(6) Pin F: +28 volt, 80-percent calibration excitation

i. Pin functions for resistance-bulb temperature transducers are shown in figures 11-19 and 11-20.

j. Only absolute pressure transducers are used.

PIN	FUNCTION
A	LOW (NORMAL POSITION)
B	WIPER
C	HIGH (ACTUATED POSITION)
D	CASE GROUND (WHEN USED)



J2-1-10

Figure 11-18. Potentiometer-Type Transducer Schematic (Typical)

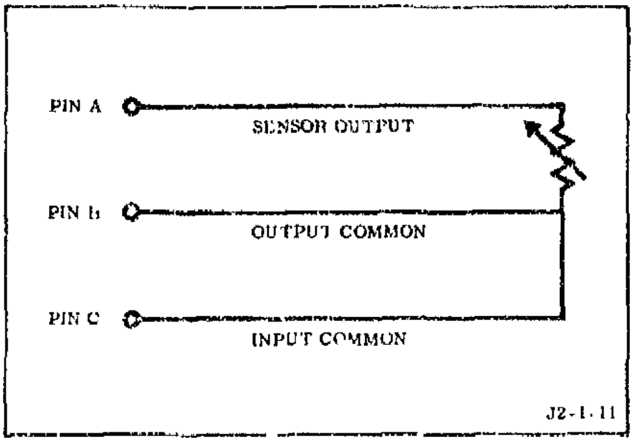


Figure 11-19. Resistance-Bulb Temperature Transducer Schematic (Typical)

11-7. PUMP INLET MEASUREMENTS.

11-8. To fully evaluate the propulsion system during flight, the vehicle manufacturer must supply instrumentation for measuring the oxidizer and fuel pump inlet pressure and temperatures. These parameters are not included with the engine system, since the measurements must be taken in the vehicle ducting. The instrumentation pick-off points should be located adjacent to the engine propellant duct flanges.

11-9. TURBOPUMP TACHOMETERS.

11-10. Both turbopumps are equipped with magnetic pickups to measure turbopump speed and to provide a turbine overspeed cutoff signal for static testing. The magnetic pickups are utilized to provide turbopump speed for the instrumentation system. The output of the magnetic transducers is designed for generation of a 1-3 volt pulse suitable for direct telemetry. The fuel turbopump rotor is fabricated from K-monel, which does not exhibit magnetic qualities until chilled to -300° F. Therefore, checkout of the tachometer by spinning the turbopump is not feasible at ambient temperatures. Electrical checkout can be accomplished, however, by applying a voltage to the checkout coil and inducing a voltage in the signal coil. This check may be made at either ambient or cryogenic temperatures.

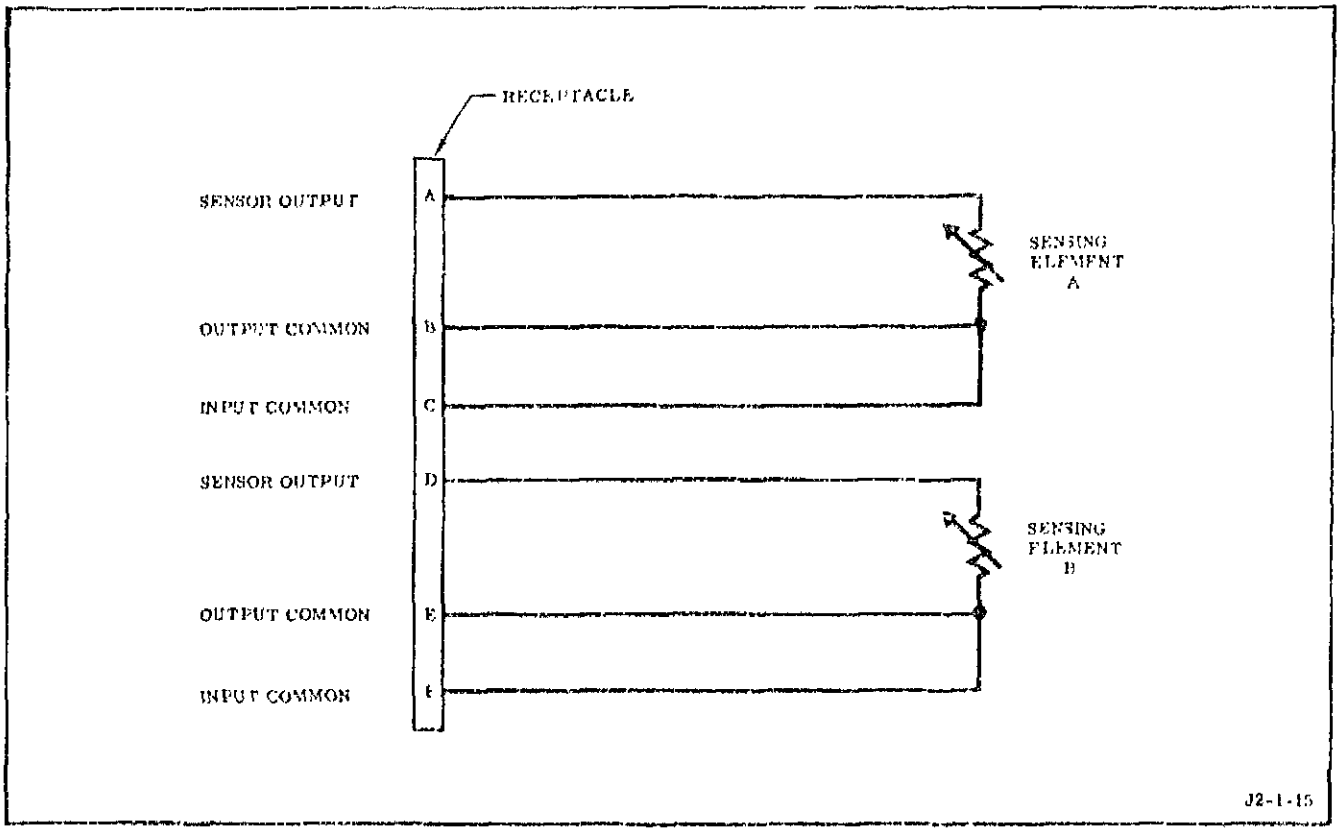


Figure 11-20. Resistance-Bulb Dual-Element Temperature Transducer Schematic (Typical)

11-11. VALVE POSITION INDICATORS.

11-12. The primary flight instrumentation has the capability of providing a position indicator signal for the MOV, MFV, GG control, OTBV, STDV, PU valve, ASI, and propellant bleed valves. The position indicators on the components are 2,000-ohm potentiometers and/or position switches. Voltage ratio is used to determine potentiometric valve positions. Voltage ratio is obtained from the telemetry potentiometer signal and is calculated from the formula

$$\text{Voltage ratio} = \frac{\text{Potentiometer output in volts}}{\text{Potentiometer input in volts}}$$

Voltage drop between the power supply and the engine interface must be accounted for when determining potentiometer input.

11-13. PROPELLANT FLOW MEASUREMENT.

11-14. Flowmeters are provided within the high-pressure propellant discharge ducts to measure main fuel and main oxidizer flowrates. The basic element of the flowmeter is a helical-vaned rotor which is turned by propellant flow to measure flow velocity. The flow diameter is closely controlled to permit accurate determination of the volumetric flowrate. Within the fuel flowmeter is a four-vane rotor which produces four electrical impulses per revolution and turns approximately 3,600 rpm at nominal flow. The oxidizer flowmeter includes a six-vane rotor which produces six electrical impulses per revolution and turns approximately 2,400 rpm at nominal flow. The output of the magnetic transducers is designed for generation of a 1-3 volt pulse suitable for direct telemetry. Electrical checkout of the flowmeter can be accomplished by supplying a voltage to the checkout coil and inducing a signal in the measurement coil. Oxidizer and fuel flowmeters have redundant magnetic pickups for stage static-test instrumentation.

11-15. INTERCONNECTING HARNESS ASSEMBLIES.

11-16. Flexible armored harness assemblies are provided for connecting the various transducers, where applicable, to their respective instrumentation packages, and the necessary vehicle-to-engine interface at a customer connect point.

11-17. PRESSURE MEASUREMENT.

11-18. Engines are delivered with dual-seal instrumentation bosses. (See figure 11-21.) The seals utilized between the bosses and transducers or transducer lines are Naflex seal 404659 for nominal and low-temperature applications, and Naflex seal 404661 for temperatures in excess of 160° F. If the dual-seal instrumentation bosses are not utilized, plugs are provided. The plugs contain a vent hole that alines with the intermediate vent between two concentric seal surfaces on the Naflex seal.

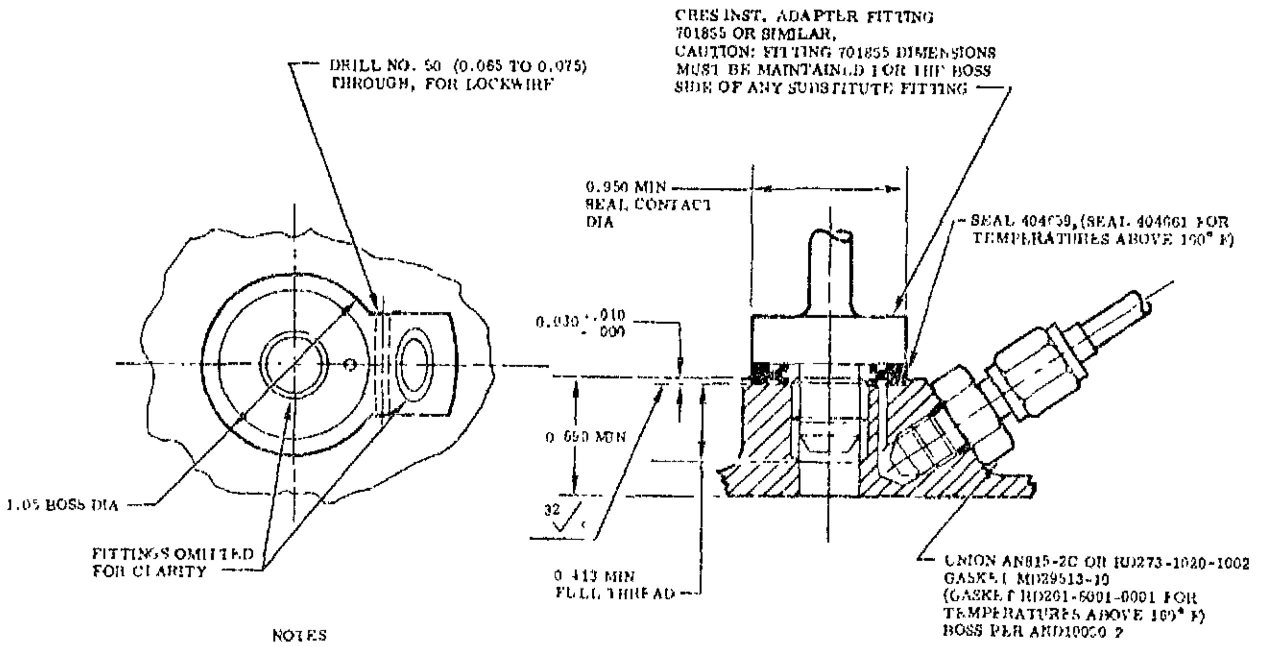
11-19. The seal vent port in the plug head is plugged with plug RD273-1020-1002, or a dimensionally equivalent plugs, and O-ring MS29513 or solid copper gasket RD261-6001-0001. The port is used to check for primary seal leakage under the plug. A tube is connected to the port and routed to a leakage-monitoring device.

11-20. TEMPERATURE MEASUREMENT.

11-21. Figure 11-22 illustrates a typical temperature transducer installation. Temperature transducer NA5-27215 is directly installed in boss 405859. Naflex seal 404666-7 is utilized to effect a seal. Leak-detection features identical to the dual-seal pressure boss are provided.

11-22. Transducers utilized in the GG exhaust system are mounted in the same manner as transducer NA5-27215 (paragraph 11-21), except that seal 404681 is used when the temperature range is in excess of 160° F.

11-23. A thermocouple monitor is provided for sensing a GG temperature during static test. It is recommended that an overtemperature cutoff device be used in conjunction with the temperature signal for all static firings.



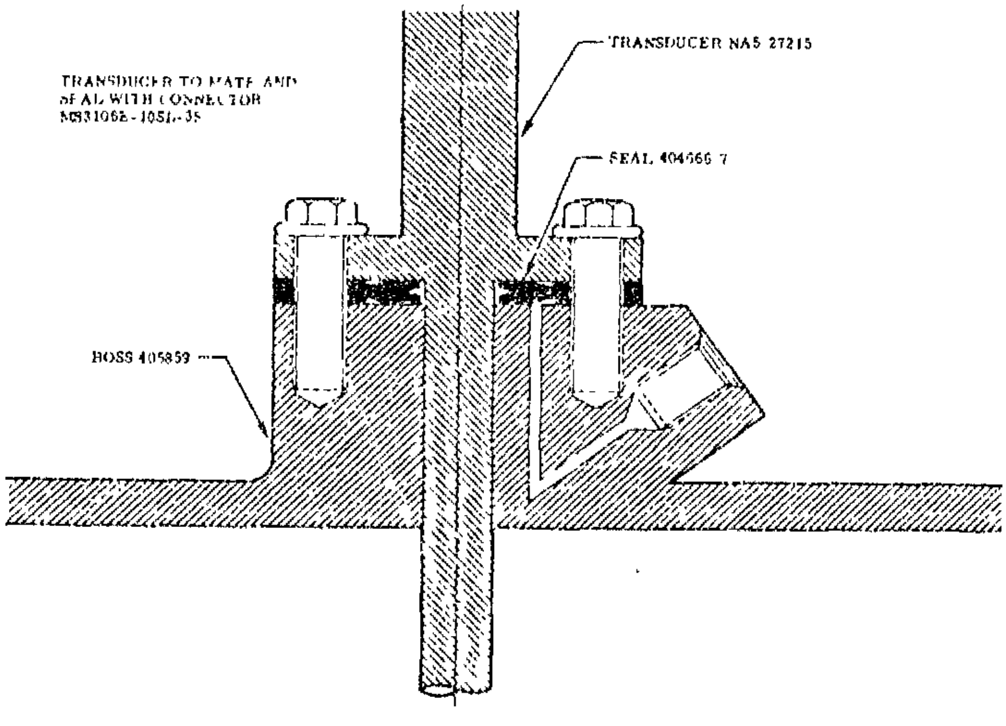
NOTES

1. ALL REFERENCE TO PART NUMBERS DESIGNATE ROCKETDYNE DRAWINGS

2. TORQUE VALUES, FOR 1/8 TUBE SIZE, TORQUE FITTING TO 10-16 IN. LBS
FOR 1/4 TUBE SIZE, TORQUE FITTING TO 38-42 IN. LBS

J2-1-77

Figure 11-21. Dual Seal Instrumentation Boss for Pressure Measurements (Typical)



J2-1-78

Figure 11-22. Temperature Transducer Installation (Typical)

11-24. STAGE STATIC-TEST MEASUREMENTS.

11-25. On engines not incorporating MD150, MD280, or MD281 change, connections are provided for 17 additional instrumentation pressure measurements for stage static test. Mounting provisions are made for the transducers, and the engine is delivered with dummy transducers in place to seal and provide stability for the lines. The dummy transducers are removed and the following transducers are installed by the vehicle contractor:

a. Oxidizer turbopump bearing coolant (PO7). (Removed on engines incorporating MD269, MD282, MD296, MD313, MD314, or MD315 change.)

b. Thrust chamber (CG1). (Removed on engines incorporating MD303 or MD304 change.)

c. Helium tank (NN1)

d. Start tank (TF1)

e. Helium regulator outlet (NN2)

f. GG oxidizer injector and purge (GO5)

g. Oxidizer turbine outlet (TG4)

h. Fuel turbopump balance piston (PF5)

i. Oxidizer turbopump primary seal (PO6)

j. GG fuel injector and purge (GF4)

k. Fuel turbopump discharge (PF2)

l. Thrust chamber (CG1a)

m. Main fuel injection (CF2a). (On engines incorporating MD237 change, CF2a becomes CF2 stage static test and is teed to the flight CF2 instrumentation sensing line.)

n. GG combustion chamber (GG1a). (Removed on engines incorporating MD237 change.)

o. ASI combustion chamber (IG1). (Removed on engines incorporating MD192 or MD246 change.)

p. Oxidizer pump discharge (PO2). (On engines incorporating MD237 change, PO2 becomes PO3 stage static test and is teed to the flight PO3 instrumentation sensing line.)

q. OTBV nozzle inlet (TG8). (Removed on engines incorporating MD226 or MD237 change.)

NOTE

> On engines incorporating MD150, MD280, or MD281 change, all instrumentation lines and transducer mounting provisions added by the MD88 or MD111 change are removed from the engine as well as the two redundant magnetic pickups installed on the flowmeters.

11-26. GAS GENERATOR OVERTEMPERATURE TRANSDUCER MATING CONNECTOR TO CABLE JOINT REQUIREMENTS.

11-27. The following is the recommended connector, wire, and method for joining the wire to the connector of the drag-in cable for the GG overtemperature transducer:

a. The following is a list of recommended equipment:

(1) Connector RD414-1013-1002 (recommended because of its torquing capability), or equivalent.

(2) Stranded thermocouple wire WC69673 (Revere Corp of America), or equivalent.

(3) Toolkit 11-3695 (Bendix), or equivalent, for removing pins from connector.

(4) Toolkits 11-2675 and 11-7345 (Bendix), or equivalent, for reinserting connector contacts.

(5) Adapter plate 11-7314-11 and locating gage 11-7313-1 (Bendix), or equivalent, for checking proper position of the pins.

(6) Epoxy resin, Epon 828 (Shell Chemical Co), or equivalent, for potting area around contacts after pins are in place.

(7) Flux: potassium fluoroborate (grade technical) 75-77 percent by weight, ethyl alcohol 2-3 percent by weight, and remainder of deionized or distilled water.

(8) Braze filler metal consisting of:

(a) Silver (AG), 56 percent

(b) Copper (Cu), 22 percent

(c) Zinc (Zn), 17 percent

(d) Tin (Sn), 5 percent

NOTE

This alloy may be obtained from Handy and Harman Co or American Platinum and Silver, Division of Engelhard Industries, Inc.

b. Using proper tool, remove pins from connector.

c. Clamp connector contact on a chill block to prevent damage to socket contact spring from high temperature.

d. Using proper flux and filler alloy, torch-braze wire to contact.

e. Using proper tools, insert connector contacts into connector from brazed-wire side.

f. Check for proper positioning of pins.

g. After pins are in place, pins must be secured by potting area around contacts to a depth of 0.03 to 0.06 inch.

11-28. INSTRUMENTATION POWER REQUIREMENTS.

11-29. Direct current power is used for operation of the flight instrumentation system. Power definitions and requirements are listed in figure 11-23.

Flight or Flight Simulation Power:	a. Primary instrumentation system power:	
	(1) Pressure transducers	24 watts maximum (at 32 vdc) with a voltage range of 24-32 vdc; 1.54 watts maximum additional for each electrical simulation (transducer simulation) during period of electrical simulation
	(2) Valve position potentiometers	0.5 watts maximum, continuous at 5 vdc
	(3) Valve position switches	2.0 watts maximum, at 24-32 vdc for each closed switch
	(4) Temperature transducers	Depends on stage circuitry. (See figures 11-2, 11-4, 11-9, and 11-11.)
	b. Auxiliary instrumentation system power:	
	(1) Pressure transducers	46 watts maximum (at 32 vdc) with a voltage range of 24-32 vdc; 1.54 watts additional for each electrical simulation (transducer simulation) during period of electrical simulation
	(2) Temperature transducers	Depends on stage circuitry. (See figures 11-2, 11-4, 11-9, and 11-11.)

Figure 11-23. Power Definitions (Sheet 1 of 2)

Direct Current:	24-32 vdc. The dc peak ripple voltage must not exceed 0.1 volt measured with a peak-reading VTVM in series with a 4.0-microfarad capacitor. The higher of the two values, measured when the voltmeter is successively connected for each of the two polarities, must be considered when determining the ripple voltage.
Alternating Current:	During checkout, ac voltages required for obtaining electrical simulation on the pump speed transducers and the main propellant flowmeters are as follows: a. 0.2 watts maximum for each coil during period of simulation at 10 vac, single phase, 200 ±0.2 cps for the flowmeter-pickup simulation b. 0.2 watts maximum during period of simulation at 10 vac, single phase, 5,850 ±5 cps for the fuel pump speed-transducer simulation c. 0.2 watts maximum during period of simulation at 10 vac, single phase, 1,920 ±2 cps for the oxidizer pump speed-transducer simulation

Figure 11-23. Power Definitions (Sheet 2 of 2)

Pages 11-57 through 11-82 deleted.

SECTION XII

CUSTOMER CONNECTIONS

TABLE OF CONTENTS

Underlined titles denote primary paragraphs.

12-1. SCOPE. This section lists customer connection points, recommended engine-to-vehicle connecting hardware, and engine seals.

12-2. ENGINE EVELOPE DIMENSIONS.

12-3. The engine is within a basic envelope approximately 80.75 inches in diameter and 133 inches in length. Refer to Rocketdyne blueprint 106475 (customer connect interface) for detailed engine dimensions.

12-4. CUSTOMER CONNECTIONS AND SEALS.

12-5. CUSTOMER CONNECTION POINTS.

12-6. The engine has three types of customer connections: mechanical, electrical, and fluid. The vehicle contractor must obtain Rocketdyne concurrence before attaching any additional lines, brackets, clamps, or other hardware to the engine.

CAUTION

> The attaching of vehicle contractor lines, brackets, clamps, or other hardware to the engine without Rocketdyne analysis may result in reduced engine reliability.

12-7. MECHANICAL CONNECTIONS. Mechanical connections are those which are used in mounting the engine to the vehicle structure or for the attachment of accessories. They include:

a. Gimbal block mounting face.

b. No. 1 actuator attach point.

c. No. 2 actuator attach point.

d. Fuel inlet duct forward flange (gimbaled engines only).

e. Oxidizer inlet duct forward flange (gimbaled engines only).

f. Fuel turbopump inlet flange (nongimbaled engines only).

g. Oxidizer turbopump inlet flange (nongimbaled engines only).

h. Hydraulic system installation flange and brackets.

i. Vehicle-mounted electrical interface panel.

j. Base heat shield attach brackets.

12-8. HYDRAULIC PUMP MOUNTING. The vehicle hydraulic pump is installed on the oxidizer pump accessory drive and secured with nuts RD114-8005-0006, or equivalent, and washers RD153-1002-0006, or equivalent. Torque nuts to at least minimum standard torque value, but do not exceed 350 in-lb.

12-9. ELECTRICAL CONNECTIONS. The engine electrical connections are terminated independently at the stage or test stand interface panel. Electrical cable clamping blocks, which are removed from the engine during installation and mounted on the stage or test stand, transfer cable loads to the vehicle structure.

12-10. FLUID CONNECTIONS. (See figures 12-1 and 12-2.) All engine fluid lines, except main propellant ducts, are routed across the gimbal plane by the engine contractor to a common interface point where they are connected to a vehicle-mounted panel during installation. The connections are listed below:

a. Start Tank Initial Fill -- for ground filling of the engine start tank with gaseous hydrogen.

b. Start Tank Vent and Relief Valve Drain -- a drain line that is routed overboard by the vehicle contractor to prevent accumulation of hydrogen in the enclosed engine compartment.

c. Start Tank Vent Valve Control -- a vehicle pneumatic source is required to open the start tank vent valve when required for tank venting or for tank conditioning and filling.

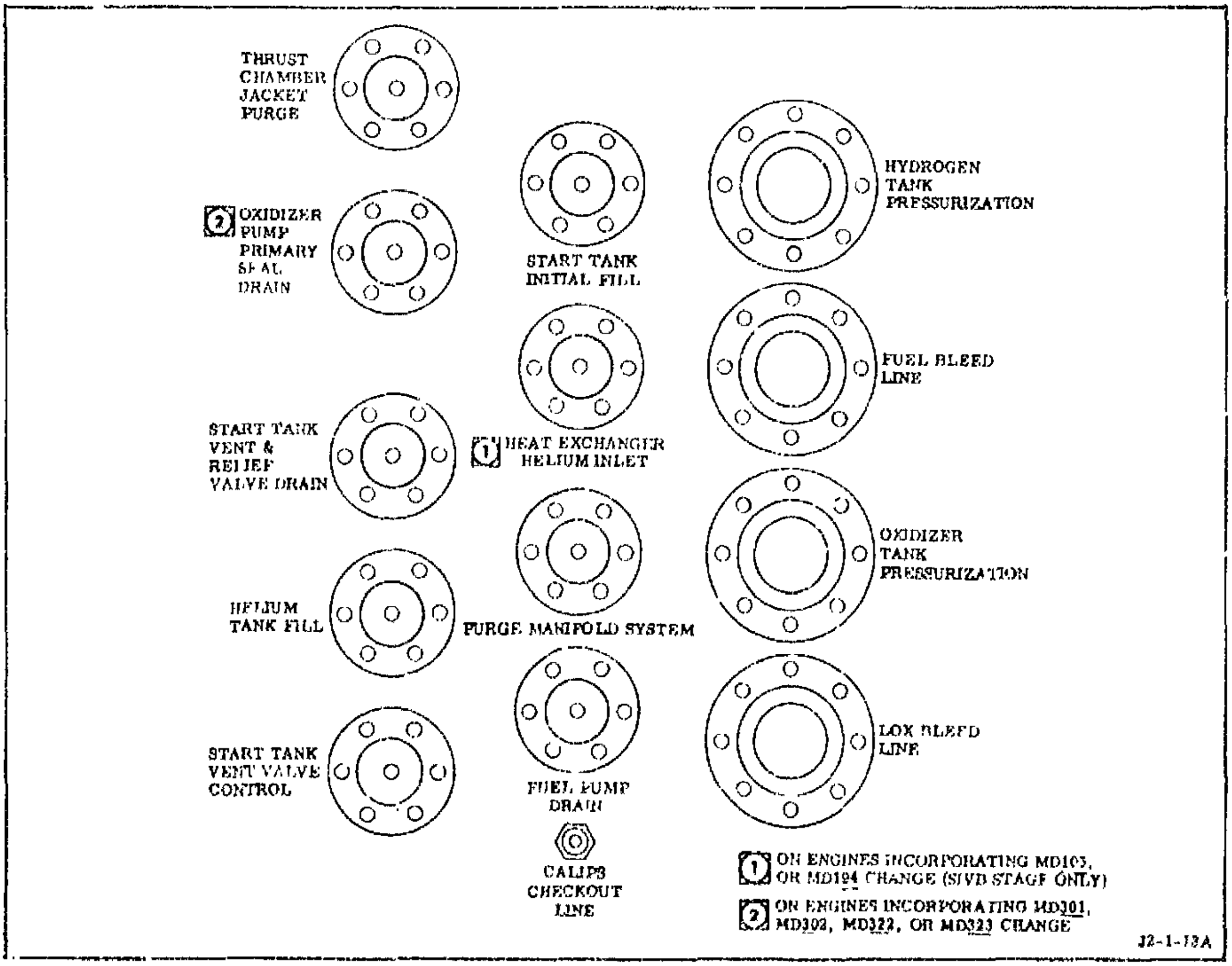


Figure 12-1. Engine Fluid Interface Panel

Interface Connection		Fluid Media	Pressure (psia)		Temperature (° F)		Flowrate		Remarks
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
Start tank initial fill	Fill	GH_2 or He (a)	1,200 (b) 1,250 (c)	1,400	-300 (b) -200 (c)	-140		N/A (f)	Start tank conditioning and filling before initial start (ground fill)(d)
	Purge	GH_2 or He		500	ambient	ambient		N/A (f)	Purge before initial fill after system has been opened. (d)
Start tank vent-and-relief valve drain		GH_2	N/A	1,400	-300	ambient	N/A	N/A	To prevent damage to the control section diaphragm, pressure in valve vent cavity must not exceed pressure in control cavity by more than 30 psid.
Start tank vent valve control		He	375	585 (e)	N/A	N/A	N/A	N/A	Start tank conditioning and venting (ground control); control line drying. (d)
Hydrogen tank pressurization		GH_2	Refer to curves in R-3825-1B for pressure, temperature, and flowrates.						
Oxidizer tank pressurization		GOX (SII) He (SIVB)	Refer to curves in R-3825-1B for pressure, temperature, and flowrates.						

(a) Engines incorporating MD361 change
(b) Applicable to nonrestart engines
(c) Applicable to initial start of restart engines
(d) Refer to R-3825-1B for detailed requirements.
(e) If control pressure in the range 585-621 psia is applied to start tank vent-and-relief valve more than 100 times, vent-and-relief valve must be replaced
(f) Refer to R-3825-1B for start tank maximum pressurization rates.

Figure 12-2. Fluid Interface Connections (Sheet 1 of 3)

Interface Connection		Fluid Media	Pressure (psia)		Temperature (° F)		Flowrate		Remarks
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
Helium tank fill	Fill	He	2,800	3,450	SIVB restart(d) SII and SIVB non-restart: ambient		N/A	N/A	Filling tank before initial start (ground fill)(d)
	Purge	He	0	1,500	ambient	ambient	N/A	N/A	Purge before initial fill after system has been opened (d)
Fuel bleed line		hydrogen	N/A	132	-425	ambient	(d)	(d)	Childown(d)
LOX bleed line		oxygen	N/A	132	-300	ambient	(d)	(d)	Childown(d)
Fuel pump drain	Fuel pump seal drain	hydrogen and/or He	N/A	30	-425	ambient	N/A	3.0 scfm	
	Start tank emergency vent valve drain(g)	GH_2		SIVB: 265 SII: 140	-300	-100		0.72 lb/min	Back pressure on system must not exceed 30 psia.
Purge manifold system (turbopump and GG purges)		He	82	130	50 (see remarks)	SIVB: 200 SII: 160	6 scfm nominal		SIVB restart engines: +50° F minimum (ground) and -50° F minimum (in flight)(d)

(d) Refer to R-3825-1B for detailed requirements.

(g) Engines incorporating MD320 or MD351 change

Figure 12-2. Fluid Interface Connections (Sheet 2 of 3)

Interface Connection		Fluid Media	Pressure (psia)		Temperature (° F)		Flowrate		Remarks
			Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	
Thrust chamber jacket purge	Purge	GN2 and/or He		200(h)(j) 75(i)	50(h)(j) ambient(i)	200(h) 160(j) ambient(i)	80 scfm	N/A	(d)
	Pre-chill	He		1,000	-420	-300	10 lb/min	25 lb/min	(d)
Calips checkout line		GN$_2$ or He		900	ambient	ambient	N/A	N/A	
Heat exchanger helium inlet (SIVB only)		He	0	430	-425	ambient	3.0 lb/min	20.4 lb/min	
Fuel inlet duct(k)		hydrogen	(l)	(l)	-424		See figures 8-1 and 8-2.		Maximum allowable surge pressure is 132 psia.
Oxidizer inlet duct(k)		oxygen	(l)	(l)	-298		See figures 8-1 and 8-2.		Maximum allowable surge pressure is 132 psia.
Oxidizer pump primary seal drain(m)		oxygen and/or He	N/A	22	-290	ambient(j)	N/A	3.2 lb/min	Pressure must not exceed 12 psig at 1.75 lb/min and -200° F.

(d) Refer to R-3825-1B for detailed requirements.
(h) SIVB restart engines
(i) SIVB nonrestart engines
(j) SII engines
(k) On SII stage center engines, values apply to turbopump inlet flange.
(l) Refer to R-3825-1B for pressure values.
(m) Engines incorporating MD301, MD302, MD322, or MD323 change

Figure 12-2. Fluid Interface Connections (Sheet 3 of 3)

d. Hydrogen Tank Pressurization -- gaseous hydrogen is tapped off the engine thrust chamber fuel injection manifold for vehicle fuel tank pressurization.

e. Oxidizer Tank Pressurization -- vehicle oxidizer tank pressure is supplied from the engine heat exchanger. On engines incorporating MD105 or MD194 change, the helium inlet is added and helium from the vehicle is supplied to the heat exchanger. The heat exchanger oxidizer supply line is removed and the tapoff point capped.

f. Helium Tank Fill -- for ground filling of the engine helium tank.

g. Fuel Bleed Line -- allows circulation of fuel during chilldown to achieve required quality in the engine for starting.

h. LOX Bleed Line -- allows circulation of oxidizer during chilldown to achieve required quality in the engine for starting.

i. Fuel Pump Drain -- permits routing of seal purge gases and fuel leakage overboard and provides an overboard vent for the start tank when the start tank emergency vent valve is actuated.

j. Purge Manifold System -- for purging the fuel turbopump primary seal, fuel turbopump turbine seal, oxidizer turbopump turbine seal, and gas generator fuel injector.

k. Thrust Chamber Jacket Purge -- for purging moisture from the thrust chamber, for pre-chilling the thrust chamber before start, and for purging fuel and contaminants from thrust chamber after cutoff.

l. Heat Exchanger Helium Inlet (engines incorporating MD105 or MD194 change) -- used when helium is used for vehicle oxidizer tank pressure. (Refer to step e.)

m. Calips Checkout Line -- permits function-testing No. 1 and No. 2 mainstage OK pressure switches.

n. Oxidizer Pump Primary Seal Drain (engines incorporating MD301, MD302, MD322, or MD323 change) -- a drain line that is routed overboard by the vehicle contractor to prevent accumulation of oxygen in the enclosed engine compartment.

12-11. The oxidizer turbopump primary seal drain and the fuel and oxidizer turbopump turbine seal drain are routed overboard along the thrust chamber contour to the chamber exit. On engines incorporating MD301 or MD302 change, a burst diaphragm is connected to the end of the oxidizer turbopump primary seal drain line. (The overboard primary seal drain line is teed to the line that is routed to the customer connect described in paragraph 12-10, step n.) These lines affect interface with respect to engine envelope and heat shield. (Refer to Rocketdyne blueprint 106475.)

12-12. REQUIREMENTS FOR INSTALLATION OF SUPPORTS ON FLUID LINES (SII STAGE CENTER ENGINES). During installation of the center engine into the SII stage, it is necessary to remove some of the engine flexible line supports to aid installation of the engine. When stage-supplied supports are installed on the engine, observe the following:

a. Installation of fuel bleed, oxidizer bleed, and oxidizer tank pressurizing lines. (See figure 12-3.)

(1) Offset dimensions must not exceed 4 inches.

(2) An adjustment or swing mount must be provided at first mounting point off engine. This will ensure there is no axial preload caused by engine thrust allnement, engine build-up tolerances, or vehicle build-up tolerances.

b. The following minimum bend radii, based on flexible line size, must be observed:

Interface Line	Minimum Bend Radius Inside Diameter (Inches)	Minimum Bend Radius to Centerline (Inches)
Oxidizer bleed	7.25	8.00
Oxidizer tank pressurization	6.88	7.50
Fuel bleed	9.00	10.00
Fuel pump drain	2.77	3.00
Purge manifold system	3.93	4.25
Start tank initial fill	5.33	5.75
Start tank vent valve control	2.77	3.00
Helium tank fill	2.77	3.00
Start tank vent and relief valve drain	5.33	5.75

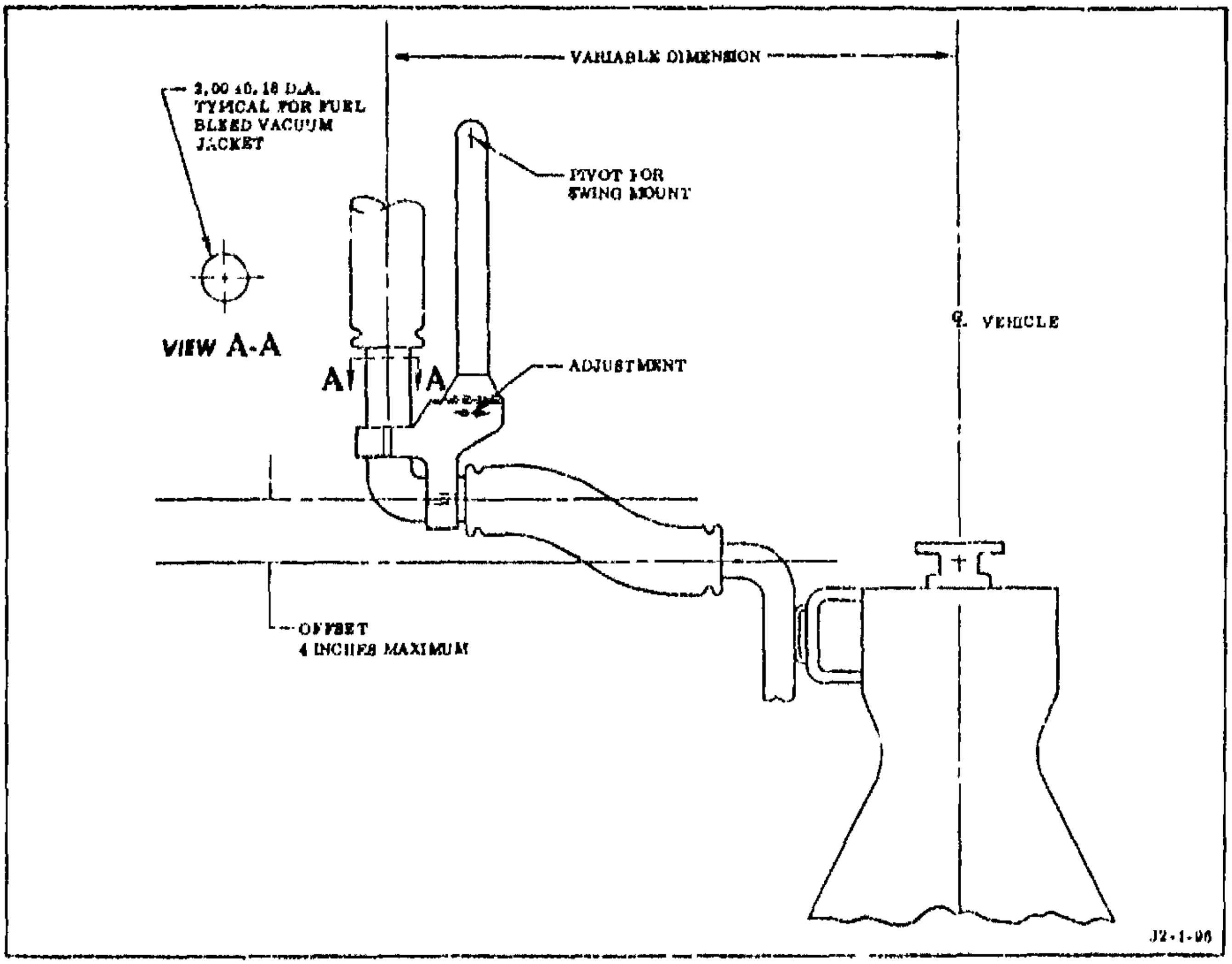


Figure 12-3. Requirements for Installation of Support on Fluid Lines (SII Stage, Center Engines)

Interface Line	Minimum Bend Radius Inside Diameter (inches)	Minimum Bend Radius to Centerline (inches)
Thrust chamber jacket purge	5.33	5.75
Oxidizer pump primary seal drain	3.08	3.50
Calips checkout	2.77	3.00

c. Flexible sections must not be installed in a twisted configuration since a twist tends to unwind when pressurized, putting torsional loads on flexible line.

d. Lines must be supported by clamps on hard tube section between flexible sections. Rigid clamping of flexible lines on flexible portion must be avoided.

e. When flexible sections are restrained to prevent chafing against each other, the following must be observed:

(1) Clamping or spacing device must be oversized and lined with a material that will not cause chafing.

(2) Materials used in clamping must be compatible with temperature extremes ranging from -410° to +200° F, depending on line involved.

(3) Weight of clamping device must be supported by structure rather than by other lines.

(4) No clamping is allowed on flexible section adjacent to engine.

NOTE

The outside diameter of flexible sections may vary, depending on the line manufacturer.

12-13. ENGINE SEALS.

12-14. All separable hot-gas and propellant flanges and connections are equipped with a dual-static seal incorporating an intermediate cavity between the high-pressure and low-pressure sealing areas. The intermediate cavity may be monitored by routing a line from the cavity to a leakage-measuring device as shown in figure 12-4.

12-15. The pneumatic control system also uses the dual seal, which is monitored during leak-tests.

12-16. All interface connections between the engine and stage are designed to accommodate the dual-type seal. The seals and the seal drain bosses are not included in the engine package, with the exception of the seal drain bosses that are provided on the main propellant inlet duct interface flanges. See figure 12-5 for interface seal information and flange dimensions. All seals and connecting hardware for interface connections are furnished by the vehicle contractor. Fluid interface connection requirements are outlined in figure 12-5.

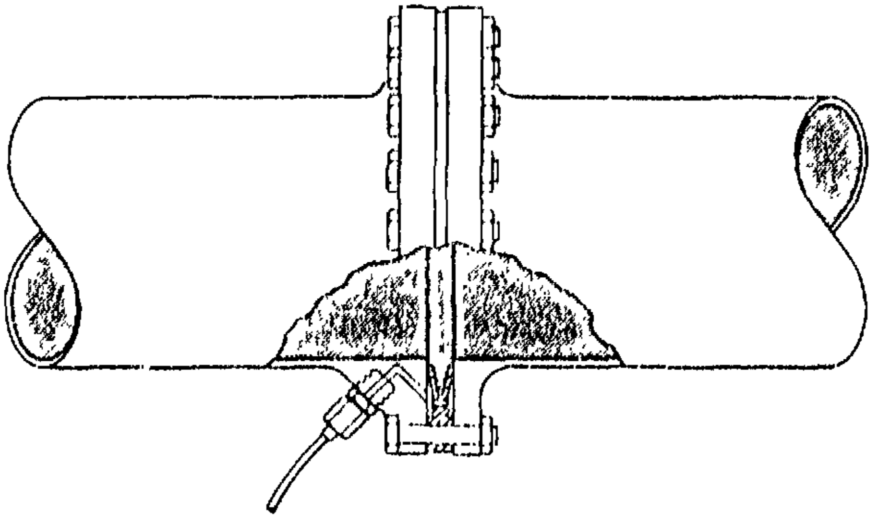


Figure 12-4. Flange Seal (Typical)

Interface Connection	Line Size (inches)	Interface Seal (Rocketdyne Usage)	Flange Thickness and No. and Size of Boltholes	Bolt Size	Bolt[a][b]	Bolt Torque (in-lb)	Washer
Start Tank Initial Fill	1/2	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Start Tank Vent-and-Relief Valve Drain	1/2	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Start Tank Vent Valve Control	1/4	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Hydrogen Tank Pressurization	1-1/2	408761	0.593 8-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Oxidizer Tank Pressurization	1-1/4	408761	0.691 8-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Helium Tank Fill	1/4	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Fuel Bleed Line	1-1/2	404673-35	0.593 8-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
LOX Bleed Line	1-1/2	404673-35	0.593 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Fuel Pump Drain	1/4	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Purge Manifold System	3/8	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent

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(a) Initial bolt lubricant is Dry-Lube. No more than one installation of a bolt is allowed without recoating bolt with dry-film lubricant RB0140-007 (Rocketdyne).

(b) Bolt strength is 140,000 psi.

Figure 12-5. Fluid Interface Connection Requirements (Sheet 1 of 2)

Interface Connection	Line Size (inches)	Interface Seal (Rocketdyne Usage)	Flange Thickness and No. and Size of Boltholes	Bolt Size	Bolt[(a)(b)]	Bolt Torque (in-lb)	Washer
Thrust Chamber Jacket Purge	3/8 1/2[(c)]	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Calips Checkout Line	1/4	E-nut					
Heat Exchanger Helium Inlet (SIVB only)	3/4	404673-23	0.531 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Oxidizer Pump Primary Seal Drain[(d)]	1/2	404673-13	0.500 6-9/32	1/4-28	RD111-1009-34XX	60 ±5	RD153-5001-0004, or equivalent
Fuel Inlet Duct	8	404656-47	0.625 deep 24-3/8	3/8-24	RD111-1009-36XX	200 ±10	RD153-5001-0006, or equivalent
Oxidizer Inlet Duct	8	404656-47	0.44 24-3/8	3/8-24	RD111-1009-36XX	200 ±10	RD153-5001-0006, or equivalent
SII Stage Center Engine: Fuel Turbopump Inlet Flange	8	404656-17	0.500 24-13/32	3/8-24	RD111-1009-36XX	200 ±10	RD153-5001-0006, or equivalent
SII Stage Center Engine: Oxidizer Turbopump Inlet Flange	8	404656-19	0.45 deep 36-5/16	5/[illegible]	RD111-1009-35XX	110 ±10	RD153-5001-0005, or equivalent

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(a) Initial bolt lubricant is Dry-Lube. No more than one installation of a bolt is allowed without recoating bolt with dry-film lubricant RB0140-007 (Rocketdyne).

(b) Bolt strength is 140,000 psi.

(c) Engines incorporating MD190 change

(d) Engines incorporating MD301, MD302, MD322, or MD323 change

Figure 12-5. Fluid Interface Connection Requirements (Sheet 2 of 2)

Pages 12-11 and 12-12 deleted.

SECTION XIII

OPERATING INSTRUCTIONS

13-1. Operating instructions for the J-2 rocket engine are in R-3825-1B.

MANUAL DATA SUPPLEMENTS

Manual Data Supplements are issued from time to time to communicate important and urgent information concerning the equipment covered in this manual. These supplements bear an identifying number and should be filed in this Appendix.

Manual Data Supplements directly affect the data in this manual and will be incorporated into this manual during a future updating effort.

A Manual Data Supplement Record is issued periodically to indicate the status of supplements issued for this manual. The status of each supplement is indicated in the "Supplement Status" column. For active supplements, no status is entered. For incorporated supplements, "Incorporated" is entered.

Upon receipt of a Manual Data Supplement, make an appropriate reference to the supplement in the margin next to the data supplemented and enter the number, date, and subject matter of the supplement on the Manual Data Supplement Record.

MANUAL DATA SUPPLEMENT RECORD

This Manual Data Supplement Record indicates the status of supplements issued for Technical Manual R-3825-1. Supplements that have been incorporated into this manual shall be removed from the Appendix and destroyed.

Supplement Number	Dated	Description	Supplement Status
1	16 July 1965	Adds precautions to protect GSE electrical circuits.	Incorporated
2	28 July 1965	Adds removal of oxidizer turbine bypass valve orifice.	Incorporated
3	1 September 1965	Adds requirements for installation of supports on fluid lines (SII stage, center engine).	Incorporated
4	10 September 1965	Changes engine stage static-test operating requirements.	Incorporated
R-3825-1-5	12 October 1965	Changes torque value for diffuser installation.	Incorporated
R-3825-1-6	29 October 1965	Adds engine start tank emergency depressurization requirements.	Incorporated
R-3825-1-7	12 November 1965	Adds main oxidizer valve actuator temperature to engine operating limits.	Incorporated
R-3825-1-8	7 March 1966	Revises figure 10-8.	Incorporated

MANUAL DATA SUPPLEMENT RECORD
(continued)

Supplement Number	Dated	Description	Supplement Status
R-3825-1-9	7 March 1966	Adds requirements for electrical interface connectors	Canceled
R-3825-1-10	17 March 1966	Adds hydraulic pump installation requirements.	Incorporated
R-3825-1-11	28 March 1966	Changes valve operating times.	Incorporated
R-3825-1-12	13 April 1966	Changes main oxidizer valve operating times.	Incorporated
R-3825-1-13	19 September 1966	Adds requirements for handling, installing, and removing pressure-actuated (Naflex) seals.	Incorporated
R-3825-1-14	8 December 1966	Adds requirement to leak-test start tank discharge valve piston and piston lip seals.	Incorporated
R-3825-1-15	5 December 1966	Adds new gimbal bearing cycle limitations.	Incorporated
R-3825-1-16	16 December 1966	Changes oxidizer dome purge requirements.	Incorporated
R-3825-1-17	21 December 1966	Adds requirement to replace the augmented spark igniter line supporting clamp and bracket.	Incorporated
R-3825-1-18	11 January 1967	Adds requirement to leak-test STDV swing gate and to measure pressure in spark igniter cables.	Incorporated
R-3825-1-19	27 January 1967	Adds requirement to purge ASI chamber pressure instrumentation line.	Replaced by Supplement R-3825-1-20
R-3825-1-20	20 February 1967	Provides installation procedure for ignition detector probe 500750 and adds requirement to remove moisture from ASI chamber pressure instrumentation line.	Incorporated
R-3825-1-21	24 February 1967	Adds requirement to pressure-decay-test mainstage OK pressure switches.	Replaced by Supplement R-3825-1-22

MANUAL DATA SUPPLEMENT RECORD
(continued)

Supplement Number	Dated	Description	Supplement Status
R-3825-1-22	2 March 1967	Changes requirement for pressure-decay-testing mainstage OK pressure switches.	Incorporated
R-3825-1-23	25 August 1967	Adds page numbers to List of Effective Pages and changes page numbers in Table of Contents of section VII.	Incorporated
R-3825-1-24	24 April 1969	Adds 200-series dash numbers to and updates engine effectivity of ECA interchangeability data.	Incorporated
R-3825-1-25	25 November 1969	Changes fluid interface requirements to add reference to R-3825-1B for start tank maximum pressurization rates.	Incorporated

Pages A-5 and A-6 deleted.

MANUAL DATA SUPPLEMENT NO. R-3825-1-26
Sheet 1 of 1 23 April 1973

This supplement affects the data in Technical Manual R-3825-1. Make a reference to this supplement in the margin next to the data being supplemented; enter the number, date, and subject matter of the supplement on the Manual Data Supplement Record; and file this supplement in the Appendix to this manual.

This supplement changes the accuracy of transducers in the auxiliary FI package.

On page 11-50A/11-50B, paragraph 11-6, replace the first sentence of step a with the following sentences:

a. The accuracy of each parameter at the output of the engine-supplied instrumentation system will be within ±2.0 percent in a temperature range of +130° to -65° F. In addition, pressure transducers in the auxiliary FI package will be within ±3.0 percent in a temperature range of -65° to -85° F.